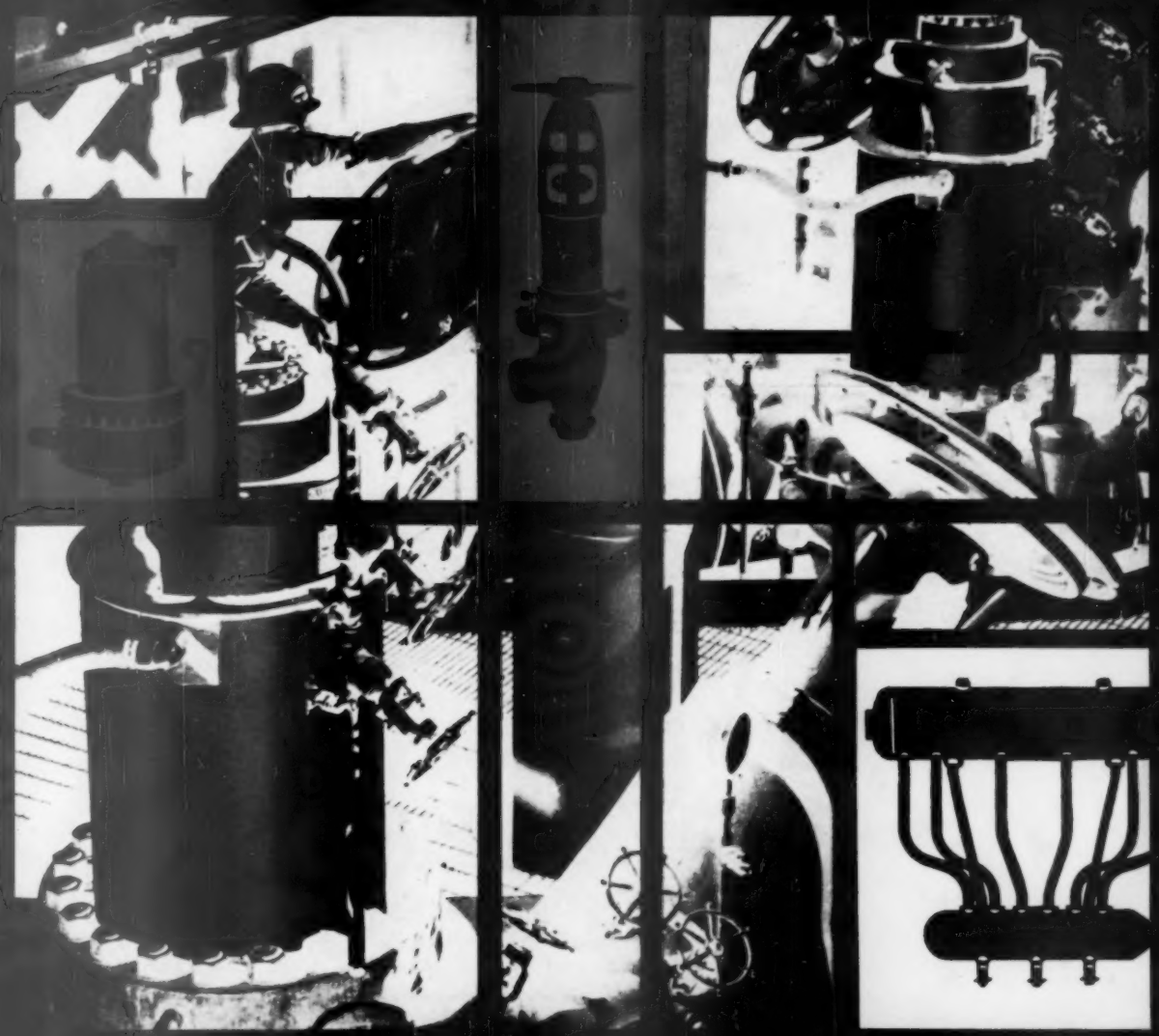
JULY 1961

NUCLEONICS

APPLIED RADIATION • ATOMIC POWER • NUCLEAR ENGINEERING



PUMPS, VALVES AND HEAT EXCHANGERS:

HOW EXPERIENCE AFFECTS THEIR DESIGN... PAGE 53

A McGraw-Hill Publication • One Dollar

X-RAYING LARGEST STAINLESS STEEL "HOT" PUMP CASTING

Above, technicians mark segment of casting for one of many hundreds of X-ray pictures employing a 24,000,000 volt Betatron at the Bonney Floyd Foundry. *Below*, X-ray picture is carefully inspected for flaws.

Shown here is the largest single-piece stainless steel pump casting built today. The X-ray procedure is just one of the many inspections necessary to assure the high quality in Worthington nuclear pumps. Special designs were necessary to allow a single casting to be made for this size pump.

A more complete discussion of special equipment criteria and manufacturing techniques for nuclear requirements is available in a Worthington pamphlet, "Manufacturing For a Nuclear Power Plant." Ask for RP-1092.

To provide the special attention required to engineer and manufacture nuclear products, Worthington has an Advanced Products Division which specializes in pumps and other equipment for nuclear plants. For further information, write Worthington Corporation, Nuclear Department 106-7, Harrison, New Jersey.

WORTHINGTON

PRODUCTS THAT WORK FOR YOUR PROFIT

CRITICAL WITH 78% D_2O...

Essential Key to Long Lived Core

Successful SSCR experiment proves ability to control excess reactivity without a multitude of neutron-consuming control rods. In full size plants only 66% D_2O is required for initial criticality.

A variation of the proven Pressurized Water Reactor, the SPECTRAL SHIFT CONTROL REACTOR, conceived by B&W, employs a variable mixture of heavy and light water to compensate for fuel burnup and accumulation of fission products during the lifetime of a given core. Conservation and full use of neutrons yields a core life of 800 full power days. Expensive shutdowns, refueling operations, and reprocessing costs are minimized.

In the size range of 300,000 Kwe to 400,000 Kwe, the SSCR, which involves no major unknowns, can be built and operated with certainty today at costs competitive with fossil fuels in many areas.

Evidence produced by B&W's experiments — under sponsorship of the United States Atomic Energy Commission — provides the highest available degree of confidence in nuclear reactors for the production of electrical energy.

For further details, contact The Babcock & Wilcox Company, 161 East 42nd Street, New York 17, New York.

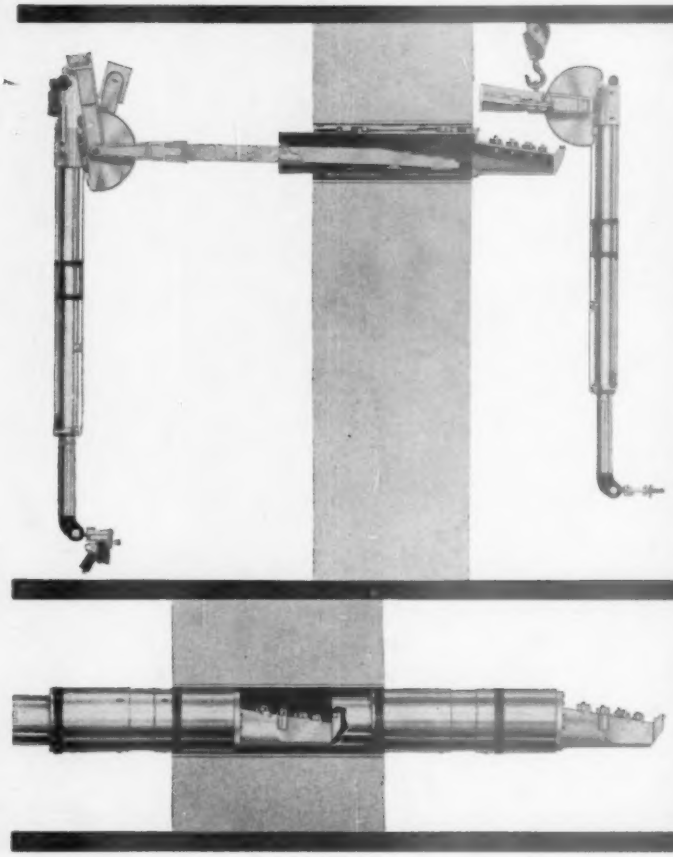
AE-84

B&W

THE BABCOCK & WILCOX COMPANY
NUCLEAR POWER APPLICATIONS

NEW . . . for high-level alpha-gamma hot cells—for handling pyrophoric, highly toxic gaseous or airborne particulate materials—wherever complete atmospheric control, prevention of dissemination by explosion or other accident is essential . . .

complete containment is provided by central research model A sealed manipulators



Sensitive and reliable, Model A manipulators are designed for dextrous, positive control and complete containment with shielded enclosures.

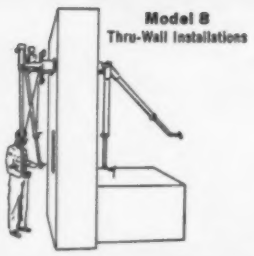
CONSIDER THESE IMPORTANT FEATURES:

SEALS—Double rotary mechanical seals between master and slave mechanisms insure reliability. Space between seals may be pressurized to monitor seal integrity. One seal is always operative even when changing seal tubes. "Push-thru" seal-tube replacement technique does not require complete wall port opening. Seal-tube features mean that all contaminated assemblies remain inside cell for disposal or decontamination and need never be brought out to the operating face.

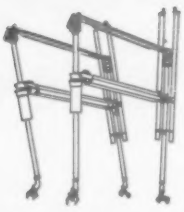
OPERATION—Careful counterbalancing, reduction of mass, friction and lost motion make forces in the ounce range sufficient to initiate all motions. Easily handles 20-pound load per arm. Bilateral drive and force reflecting design characteristics give remarkable "sense of feel," reducing training time to a minimum.

MAINTENANCE—Three standard, interchangeable subassemblies: master arm, slave arm, and seal tube, simplify maintenance. A crane and simple fixture are sufficient for remote connection or removal of slave arm. Alignment pins assure positive slave arm positioning. All slave-end motions lock at disengagement for easy relocation.

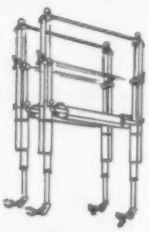
CENTRAL RESEARCH . . . MANIPULATORS FOR EVERY NEED



Model 8
Thru-Wall Installations



Model 7
Restricted Space Installations



Model 4
Over-Wall Installations

Model B
Canal Manipulator

For further information write:

Central Research
laboratories, inc.
Red Wing, Minnesota, Dept. 110

NUCLEONICS

APPLIED RADIATION • ATOMIC POWER • NUCLEAR ENGINEERING

JULY 1961 • VOLUME 19 NUMBER 7

FEATURE ARTICLES

How Experience Affects Design of Water-Cooled-Power-Reactor . . .

55 PUMPS

64 VALVES
KENNETH H. GRUENWALD

70 HEAT EXCHANGERS
GEORGE T. LEWIS, Jr., MICHAEL ZIZZA and PAUL P. De RIENZO

INSTRUMENTATION & MEASUREMENTS

82 Scintillating Beads for Aqueous Solutions; Wearable Air-Contamination Unit; Temperature, Humidity and Films

84 Locating Failed Fuel in Water Reactors
ROBERT N. OSBORNE

NUCLEAR ENGINEERING

90 Bonus Superheat Reactor Off to Good Start

92 Inspecting Fuel-Slug Cladding at Hanford Automatically
DANIEL C. WORLTON

APPLIED RADIATION

100 New Techniques Improve Detection of Tritium; A Radioactive Control for Pigeon Population? Radiotracers Test Metal Cleaning

102 Solving Design Problems for Food Irradiators

102 1. Dose Rates from Rectangular Plaques
FRED G. MOOTE

104 2. Three-Plaque, Two-Pass Irradiator
JOHN L. DONOVAN

DEPARTMENTS

NUCLEAR REACTIONS 6
NEWS OF THE MONTH 21
NUCLEAR BOOKSHELF 112
PRODUCTS AND MATERIALS 114
INDUSTRY NOTES 122
NUCLEAR CALENDAR 124
NEWSMAKERS 126
INDEX TO ADVERTISING 128

Jerome D. Luntz, Editor and Publisher

R. Hobart Ellis, Jr., Managing Editor

TECHNICAL STAFF

Thomas L. Cramer, Associate Editor
Harold L. Davis, Associate Editor
James J. Dutton, Associate Editor
Margaret Beach Glos, Assistant Editor

NEWS STAFF

John E. Kenton, News Editor
Robert E. L. Adamson, Associate News Editor

John Wilhelm, Manager, News Bureaus
Washington—G. B. Bryant, Jr., Chief, Richard A. Smith; London—John Shinn, John Tunstall; Paris—Robert E. Farrell, Arthur L. Erikson; Bonn—Peter Forbath, Silke B. McQueen; W. Berlin—Hans Plewe; Moscow—Ernest Conine; Tokyo—Sol Sanders; Rio de Janeiro—Leslie Warren; Mexico City—Peter Weaver; Melbourne—Alicija Grobtuch; Beirut—O. M. Marashian; Brussels—A. P. L. Gordon; Bombay—Sharokh Sabavala; Zurich—Raymond Shah; Johannesburg—Norman Herd; Milan—Gene DiRaimondo; Stockholm—Curt Agren; Vienna—F. H. Baer; Ottawa—Frank Flaherty

PRESENTATION STAFF

Tom Howland, Jr., Art Director
Herbert Taylor, Assistant Art Director
Barbara Keller, Production Editor

Keith Henney, Consulting Editor

•

Philip H. Hubbard, Jr.
Advertising Sales Manager

James H. Thomas, Market Research Manager
James F. O'Brien, Business Manager
Tom Howland, Jr., Promotion Manager
George Pomeroy, Classified Advertising Mgr.

ADVERTISING SALES STAFF

Donald J. Cassidy, New York
Merrill J. Hosmer, Boston
Donald C. Knapp, Philadelphia
Willis T. Smith, Chicago
Thomas K. Cogswell, Cleveland
Frederick R. Whitmore, Los Angeles
Scott Hubbard, Portland
M. Miller, Atlanta
John G. Grant, Dallas
Joseph C. Page, Houston
Jack Patten, Denver
E. E. Schirmer, Dennis McDonald, London
Stanley Kimes, Frankfurt
Michael R. Zeynel, Geneva

•

Thomas L. Cramer, Buyers' Guide Manager
James H. Thomas, Circulation Manager

...about NUCLEONICS

Manuscripts We Want to See

"There are one or two rules . . ."

—William S. Gilbert

A real pleasure in our office is a letter that says, "We have done some work and would like to publish it in NUCLEONICS. How shall we prepare the paper?" W are pleased that the writer wants to publish in our pages; we are flattered that he asks how we think he should prepare a manuscript.

There is not quite the same pleasure in composing an answer, for we never really know what to say. The good editor knows what he wants when he sees it. He's not quite so sure that he can tell an author how to produce it. In matters of taste, who can be the judge?

There are one or two rules, however, that may help the man who would like to please us with his writing:

First and basic is our conviction that what is good writing does not depend on the book in which you find it. "To be or not to be—that is the question," is simple, straightforward and direct. So is, "We connect the G-M tube through an 0.01-mfd capacitor to the preamplifier."

The message is not always easy to sell. Many are convinced that technical matters must be expressed in the impersonal passive voice, and paper after paper begins with dull sentences that can be interpreted as either the author's statement of his own work or his review of the work of others. ("Tritium-labeled thymidine has been found to be an effective biological tracer.")

Outline. We feel that the first step to clarity is to make an outline. Headings depend on subject matter. But whatever the headings and however they may change as writing progresses, an initial effort to find divisions and subdivisions is worth two rewritings at the end. Your outline headings become our crossheads and bold-face run-ins (as they're known in the trade).

Then, after you have put bricks and mortar on the framework with the clearest words you know (short sentences, sketches, paragraphs well built on good opening sentences), we would urge you to write your introduction last. Use it to tell the reader what is coming, and see that he is similarly informed at every step of the way: "although," "however," "on the other hand" for contrasting ideas; "moreover" and "since" to show agreement; general statements before detailed analysis—things like that.

Manuscript preparation we leave mainly to you. If you insist on our preference, it is for clean typing, double spacing, numbered pages, wide margins. The paper need not be pretty; a word crossed out and retyped doesn't slow us up a bit.

The NUCLEONICS author should not invest lots of time and money redrawing figures. They are almost sure to be redrawn by us. After we decide how big our reproductions will be, our experts tell us how thick the lines should be and how high the lettering.

But it really doesn't matter as long as you give us the facts (as many as possible), a lot of pictures and freedom to work with them. We can write the story ourselves or use your version, read clean copy or dirty. Just give us the facts.

A McGRAW-HILL PUBLICATION

NUCLEONICS (with which are consolidated "Atomic Power" and "Atomic Engineering"), July, 1961, Vol. 19, No. 7. Published monthly by the McGraw-Hill Publishing Co., Inc., James H. McGraw (1860–1948), founder. Executive, Editorial, Circulation and Advertising Offices, McGraw-Hill Building, 330 W. 42nd Street, N. Y. 36, N. Y. Telephone: Longacre 4-3000. U. S. subscription rate (includes Buyers' Guide issue) for individuals in the field of publication: $8 per year; $12 for 2 years; $16 for 3 years; single copies, $1. For subscription details and Canadian and foreign rates see p. 6. Printed and second-class postage paid at York, Pa., U. S. A. Title registered in U. S. Patent Office. © Copyright 1961 McGraw-Hill Publishing Co., all rights reserved. Officers of the Publication Division: Nelson L. Bond, President; Shelton Fisher, Wallace F. Traendly, Senior Vice Presidents; John C. Callaham, Vice President and Editorial Director; Joseph H. Allen, Vice President and Director of Advertising Sales; A. R. Venezian, Vice President and Circulation Coordinator. Officers of the Corporation: Donald C. McGraw, President; Joseph A. Gerardi, Hugh J. Kelley, Harry L. Waddell, Executive Vice Presidents; L. Keith Goodrich, Vice President and Treasurer; John J. Cooke, Secretary.

Postmaster. Please send form 3579 to Fulfillment Manager, NUCLEONICS, 330 W. 42nd St., N. Y. 36, N. Y.

PM-1 Airlift, on Schedule, Demonstrates Martin Capabilities

On schedule, 27 months after award of the PM-1 contract to The Martin Company by the U.S. Atomic Energy Commission, airlift of the world's first air transportable nuclear power plant to its operational site began in May.

Designed to provide 1000 kilowatts of high quality electricity suitable for operation of sensitive radar equipment, and also supply 7,000,000 Btu per hour of steam heat, the entire installation had to be air transportable.

The complete system was preassembled at the Martin plant in Baltimore. Following pre-testing of all systems, the component packages were disconnected from each other. Upon arrival at the operational site, these self contained units (on integral skids) are ready to be reconnected and put in operation. Preassembly, pre-testing and integral packaging and handling provisions insure extremely efficient on-site activation.

The portable nuclear power plant, especially designed for remote locations where transportation and storage of fuel oil for conventional power plants is difficult and expensive, will go into operation this fall at Sundance, Wyoming, where the Air Force is building a radar station on Warren Peak. This will be a rigorous test since the 6650 foot peak gets an average of more than 100 inches of snowfall a year, and temperatures drop to more than 40 degrees below zero.

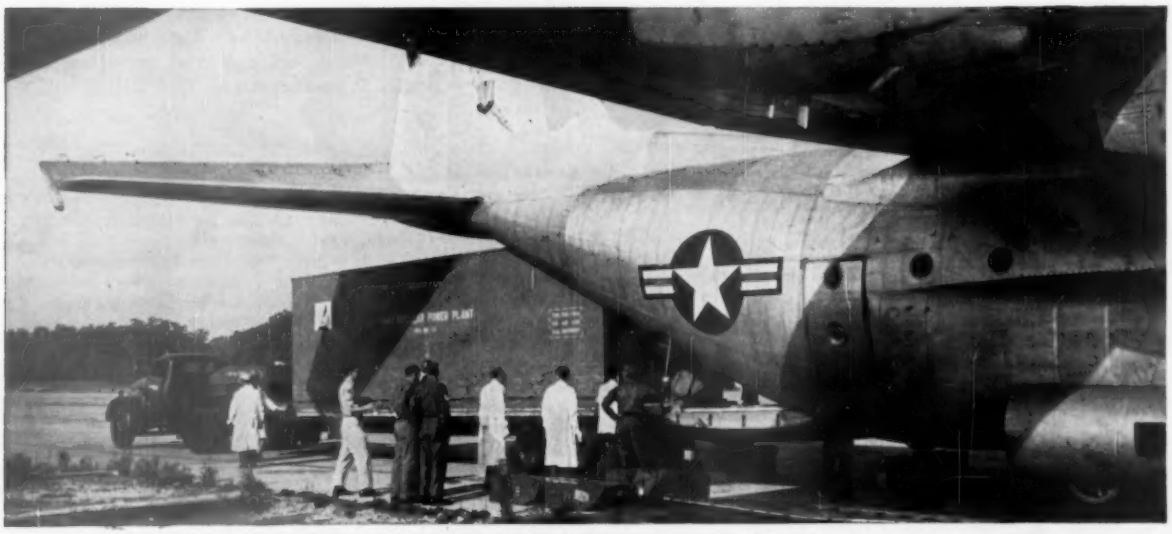
PACKAGE DESIGN CRITERIA

1. Minimum number of packages
2. Maximum package weight—30,000 pounds
3. Maximum package dimensions—8'8"x8'8"x30'
4. Maximum load distribution—1080 lbs/running foot
5. Package tie-down load factor requirements—

8g forward	1.5g vertical (up)
2g aft	4.5g vertical (down)

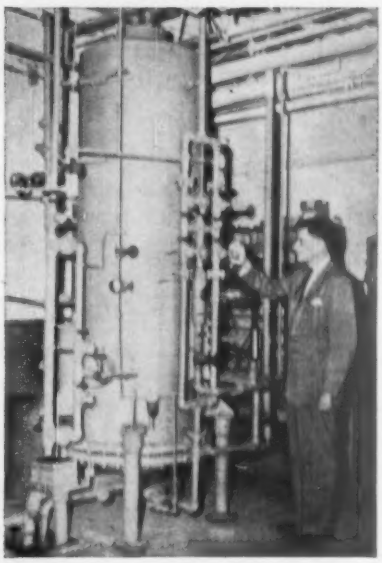
PACKAGE ARRANGEMENT

Sixteen air transportable packages required to ship basic PM-1 plant. Twelve packages contain mounted and connected equipment. When these packages are interconnected, using items shipped in the other four packages, they form the basic operational plant including an equipped maintenance shop, laboratory, decontamination, waste disposal and fuel storage facilities.



An Air Force C-130A aircraft, one of several from the 62nd Troop Carrier Squadron at Sewart AFB, Tennessee, takes the first PM-1 package aboard during the first phase of the 1700-mile shuttle run between Baltimore and the staging area near the South Dakota-Wyoming border.

BARNSTEAD MIXED-BED DEMINERALIZERS



This Barnstead MM-5 Mixed-Bed Demineralizer (1500 g.p.h.) was installed at a semi-conductor plant for critical washing and rinsing of electronic sub-component parts. The purified water produced is of high electrical resistance and free of silica and CO_2.

FOR DEMINERALIZED WATER OF HIGH ELECTRICAL RESISTANCE AND CONSTANT pH

If your manufacturing operation makes demineralized water imperative . . . contact Barnstead, since 1878 the leader in water purification equipment. Barnstead Demineralizers hold ionizable content to a maximum of one-tenth of a part per million . . . producing water of high electrical resistance with pH of the demineralized water remaining constant between 6.8 and 7.2 throughout the purifying cycle.

Operation is simple since this single column unit employs one resin bed in which cation and anion resins are thoroughly mixed. A Barnstead Purity Meter constantly monitors the water being produced . . . red light shows when the water purity is below standard . . . and the demineralizer should be regenerated.

The unit comes completely equipped with Flow Meter, Purity Meter, Pressure Gage, and all connections in place to tap raw water supply. Easy to operate and easy to regenerate . . . can be equipped with automatic regeneration controls if desired.

Catalog #160 describes the complete line of Barnstead Demineralizers in capacities up to 2500 g.p.h. Where distillation of water is a must (removal of organics, bacteria, etc.) write for Catalog "G" on Barnstead Water Stills.

Barnstead
STILL AND STERILIZER CO.
34 Lanesville Terrace, Boston 31, Mass.

NUCLEAR REACTIONS

Journalism: Whither or Whether

Here is another comment on Alvin Weinberg's article, "Authors, Readers and Publishers," that appeared in the NUCLEONICS *Spring Book Roundup in May.*

In his letter, Mr. Woodbury points out that people in the legal field for many years have had to digest an enormous mountain of literature. Their solution to the problem of what to read lies in training lawyers to develop their own critical judgment so that they can discriminate between what is of value to read and what is shoddily done. So read on to learn Mr. Woodbury's views.

DEAR SIR:

According to our tradition, any useful definition of economic freedom must be compatible with many points of view and with many interests. The gist of our tradition may be that no single interest or point of view is ever overriding. One specific which must fit under the umbrella of our tradition is free press, free journalism.

According to another tradition where there is always one overriding interest, the definition of economic freedom has a peculiar meaning that is strange to our ears. Within the confines of that tradition the specific of free press does not exist as we know it.

Both definitions are largely empirical today. They have materialism in common, which is no doubt practical because human nature is a universal common denominator. Additional common ground is limited by differences in fundamental convictions as to the merits of the carrot or the prod, incentive or fear. Yet, neither incentive nor fear is completely rejected in either case and what is more, the Press and the President are now debating whether free press has immutable status in our free economy.

The need for free, inquiring minds is of the essence to our tradition. The present need for expertness, for excellence, for clear thinking is vital.

It is important that nuclear-energy people do more reading. It is equally important for others. It is equally important that they should read widely and not only in their specialties. All that is required is interest. No one disagrees that there is a wealth of material to be read. Pity the poor man however, who has too much interest and not enough critical judgment, who tries to read everything, because he will be snowed.

The American legal profession has perhaps more pages published per man per day than any other. An important and a continuing part of a lawyer's training is learning to use the material that is and that has been printed. Every user of this material must develop an ability to judge it. Specifically, this means learning to use one's critical faculties—a very individual matter—which, one can hope, are titillated by formal education.

Subscription Information

Subscription rates (includes Buyers' Guide issue): United States $8 per year; $12 for 2 years; $16 for 3 years. Canada, other Western Hemisphere countries, and the Philippines, $10 for 1 year; $16 for 2 years; $20 for 3 years; all other countries, $15 for 1 year; $25 for 2 years; $30 for 3 years. Single copy prices: United States, U. S. possessions and Canada, $1, elsewhere, $2; Buyers' Guide issue $2 and $4.

Nucleonics is available only by paid subscription. Publisher reserves the right to refuse nonqualified subscriptions. Subscriptions to Nucleonics solicited only from individuals engaged in the design, development and use of atomic power, nuclear engineering and applied radiation. Position and company connection must be indicated on subscription orders.

Subscription correspondence and changes of address should be sent to Fulfillment Manager, Nucleonics, 330 W. 42nd St., New York 36, N. Y. Allow one month for change of address, giving old as well as new address, and including postal zone number, if any. If possible, enclose an address label from a recent issue of the magazine. Please allow one month for change to become effective.

Our primary aim is to provide subscribers with a useful and valuable publication. Your comments and suggestions for improvement are encouraged and will be most welcome. If editorial service is unsatisfactory, the publisher, upon written request, agrees to refund the part of the subscription price applying to the remaining unfilled portion of the subscription. Printed in U. S. A.

Title registered in U. S. Patent Office. Copyright 1961 McGraw-Hill Publishing Co., all rights reserved.

Published legal writing, like any other, is a combined product of authors and publishers, some of whom are objective, some not. They are largely sustained by buyers, some who are critical, some who are not. Reviewers and editors help to ensure quality. The touchstone is personal judgment.

The law, like science, has segments of activity which are publicly supported—federal, state and local courts, for example. Also, circumstances in each may be glamorous at times, as perhaps they were on occasion during the lifetimes of Darrow and Fermi. Presence of glamor in any field may serve to enhance its fashionability and hence, prolong public interest in it. The difficulty and importance, especially in science, of objective news reporting under such conditions is another interesting subject. But, glamor is not relevant in a discussion of trade journalism.

What is relevant and significant is that law writers and publishers have devised, on their own responsibility, some of the best indices for professional literature that exist. Some are both difficult and intended for limited audiences; so rewards, if any, do not appear at once. They—volumes of index material—are often of sufficient importance to merit scholarly, critical review. They are also in the free market place where thorough and objective work can survive to achieve lasting eminence and where shoddy work is eventually, discriminatingly judged.

There are, of course, many other affirmative examples which can be cited. The publishing industry can and does contribute to the growth of intellectual discipline, and its products enlarge opportunities for individual growth and scholarship for those prepared to use them. But free journalism can never take command. It can never take over science; it can never take over the law—that is, until the day that law takes over journalism.

We hope that no person under our empirical umbrella soberly urges the latter course. If someone does, we shall have a jolly good Donnybrook because there are few I-don't-care lawyers among us today and probably even fewer I-don't care journalists.

—Robert C. Woodbury
Counsellor at Law and Registered Engineer
New York, New York

CHECK THESE CAPABILITIES!

RCA

FACTORY-TRAINED SERVICE SPECIALISTS *provide*

Nationwide *On-Site* Maintenance and Calibration for All American-Made Nuclear and Scientific Instruments!

✓ INSPECT
Skilled services performed at your facility by specialized personnel from nearest RCA repair center . . . to save you time and money!

✓ DETECT
RCA nuclear and scientific service specialists factory-trained by major equipment manufacturers . . . to find the trouble fast!

✓ CORRECT
Extensive stock of factory-specified replacement parts and portable servicing gear carried by RCA specialists . . . to ensure reliable replacements and conclusive, dependable service!

E. G.

Fort Belvoir reactor training simulator . . . normally in operation 24 hours a day . . . no regularly scheduled maintenance time . . . maintained by RCA on yearly contract basis . . . results: *better than 99 per cent of scheduled training time is productive time!*

Realizing the increasing importance of nationwide service facilities, many prominent manufacturers* of nuclear and scientific equipment have contracted with RCA Service Company as an approved service representative for their products.

RCA can serve you skillfully in these areas:

- **Equipment installation and maintenance**
- **Complete facility operation**
- **Specialized engineering assistance**
- **Training and publications**

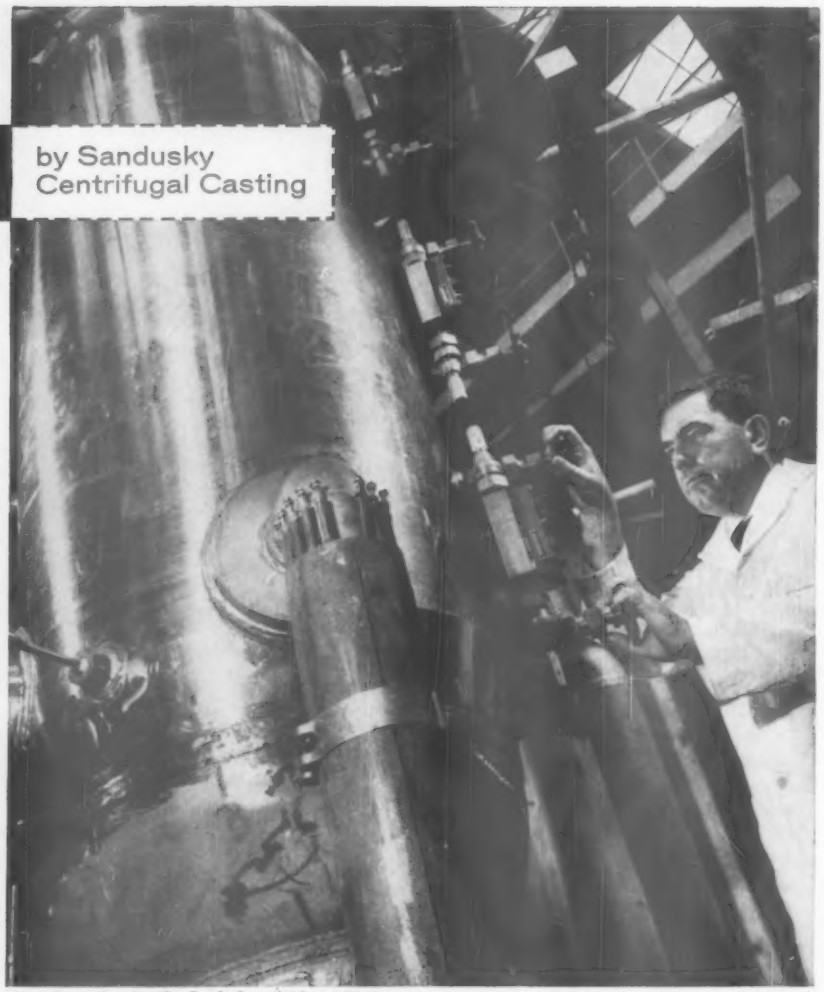
For additional information on RCA services, phone WOodlawn 3-8000, Ext. PY 6038, or write to RCA Nuclear and Scientific Services, Bldg. 206-2, RCA Service Company, Cherry Hill, Camden 8, N. J.

*Names available upon request

RCA

The Most Trusted Name in Electronics
RADIO CORPORATION OF AMERICA

SOLVED: by Sandusky Centrifugal Casting



This photo, showing the Sandusky cylinder welded into position, courtesy of the Lummus Company, New York. New York who fabricated, assembled and tested the completed loop before shipping it to the ETR site in Idaho.

Nuclear Test Loop Uses Sandusky Centrifugal Casting as Pressurizer Cylinder

A Sandusky Centrifugal Casting is the main cylindrical component of an electrically heated pressurizer, designed by Knolls Atomic Power Laboratory to Section VIII, of the ASME Code (Unfired Pressure Vessels) for use in the new Engineering Test Reactor facilities at Idaho Falls, Idaho.

This 66¼" long cylinder, 27" O.D. with walls 2½" thick, was centrifugally cast of an 18-8 stainless steel (SA-351, Grade CF-8) for the extra corrosion resistance required under nuclear loop service conditions: demineralized water at temperatures to 650°F and pressures to 2500 PSI.

O. G. Kelley Co., Boston, to whom we delivered this 2-ton, fully machined cylinder, welded on the forged heads and nozzles, radiographed the welds, and hydro tested the completed vessel to 4300 PSI.

This is another example of the adaptability of Sandusky Centrifugal Castings to applications demanding the highest order of quality. They may well offer you a practical and economical answer to your cylindrical needs, also.

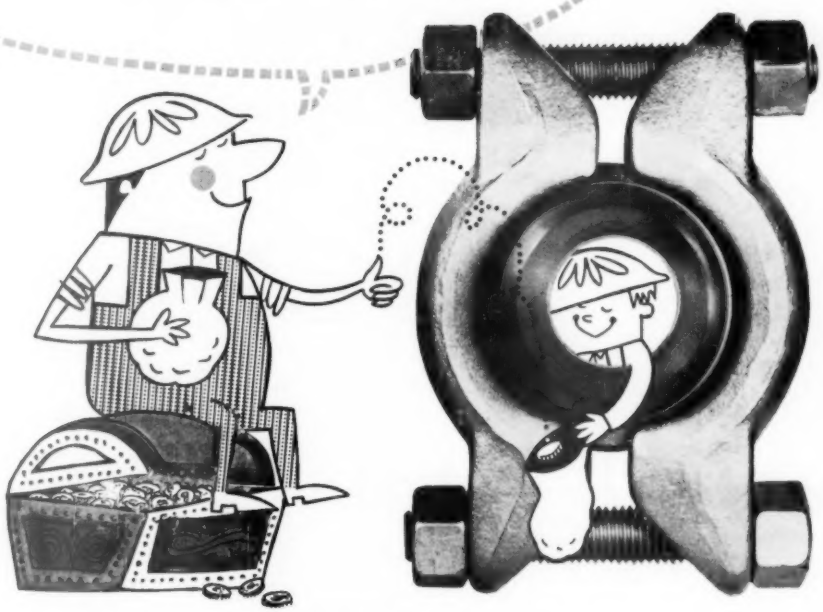
We are producing cylinders and piping in diameters from 7" to 54"—in lengths to 33 ft.—in a wide range of ferrous and non-ferrous alloys. Write for Bulletin 300, for more complete technical information on the Sandusky process and product application data.

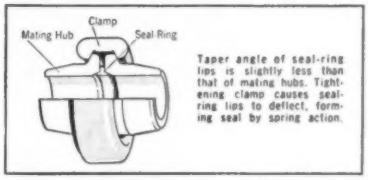
SANDUSKY ® **CENTRIFUGAL CASTINGS**

FOUNDRY & MACHINE CO.

SANDUSKY, OHIO—Stainless, Carbon, Low-Alloy Steels—Full Range Copper-Base, Nickel-Base Alloys

How Grayloc® Pipe Connections Can Save You Money




Clamp
Mating Hub
Seal Ring
Taper angle of seal-ring lips is slightly less than that of mating hubs. Tightening clamp causes seal-ring lips to deflect, forming seal by spring action.

Money isn't always measured in dollars — around a shop or plant it may be disguised as space, time, effort, weight, trouble and inventory. With GRAYLOC Pipe Connections, you're saving in all these categories.

Specifically, GRAYLOC Connections are smaller than equally rated flanges so they weigh less. With only two bolts per connection, they take less time, trouble and effort to assemble.

The completely re-usable, all metal seal ring eliminates the need for replacement gaskets, so you save again on inventory and on maintenance time. Fluctuating temperatures and pressures, external stress or vibration never lead to loose, leaky GRAYLOC Connections. After they're assembled, they never need re-tightening.

GRAYLOC Connections are manufactured in standard stock sizes from 1″ to 30″, with special sizes available on request. They can easily be made of corrosion resistant metals on short notice. To learn the complete, validated GRAYLOC story, write today for the GRAYLOC catalog.

GRAYLOC SALES DIVISION

GRAY Tool Company

P. O. BOX 2291 • HOUSTON 1, TEXAS • RIverside 7-1240

6113

Inspector measuring pole face gap to a tolerance of ±.005".

Yoke made of five forgings held together with dowels loaded to 350,000 pounds tension by a hydraulic bolt stretcher.

This mark tells you a product is made of modern, dependable Steel

259-ton magnet forgings for new 10^{15} (million billion) particles/second cyclotron

This 88-inch spiral ridge design cyclotron will permit nuclear explorations which heretofore have not been possible. The spiral ridges produce greater phase stability, prevent waste of energy. They keep the particles in focus at the tremendous speeds that are built up.

The beam current (number of particles accelerated in a given time) will be about double that of one world-famous 60-inch cyclotron and about 1,000 times that of the 184-inch synchro-cyclotron. Some million billion particles a second will be controlled by the intense, precision magnetic field created by this electromagnet.

The new machine will accelerate a variety of particles. Alpha particles (the nuclei of helium atoms) will reach a maximum of 120 million electron volts (MEV); deuterons (the nuclei of heavy hydrogen atoms) 60 MEV; and protons (the nuclei of ordinary hydrogen atoms) 30 MEV.

To meet the stability and precision requirements, designers turned to forgings. The USS Quality Forgings seen in the pictures represent about 305 tons of parts that were forged on our 10,000-ton press. After extremely accurate machining the total assembly weighed 258.8 tons.

To match magnetic properties, the pole pieces had to be from the same heat of low carbon steel, and they had to be machined, ground and polished to $\pm .005''$. The pole faces had to be parallel to within $\pm .005''$ over their entire surfaces. Steel for all 18 forgings was melted, forged, machined, heat treated and inspected at our Homestead Works. We also furnished dowels $3\frac{1}{2}''$ in diameter, hardened to Rockwell C 35 to 40, which were loaded to 350,000-pounds tension when the forgings were fastened together.

No matter what kind or size of USS Quality Forgings you buy, you get the advantages of the finest steel, the most modern equipment and the most skilled forging men in the world. Please address inquiries for our free folder on nuclear forgings to United States Steel, 525 William Penn Place, Pittsburgh 30, Pa.

United States Steel Corporation • Columbia-Geneva Steel Division • Tennessee Coal & Iron Division • United States Steel Export Company

USS TRADEMARK **United States Steel**

SCINTILLATION

PAUL-MARTIAL-151

QUARTZ PRODUCTS CORPORATION
688 Somerset Street
PO Box 628
Plainfield - New-Jersey
Tel. : Plainfield 7-4545

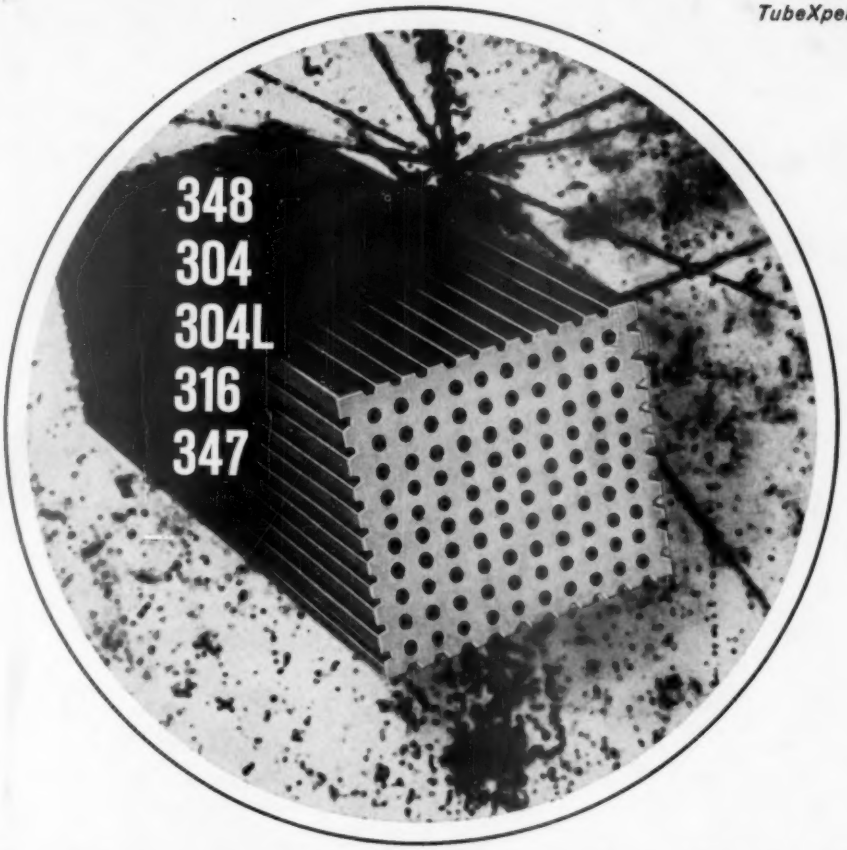
all organic and inorganic phosphors

QUARTZ & SILICE

SOCIETÉ ANONYME AU CAPITAL DE 5 495 000 NOUVEAUX FRANCS

8, RUE D'ANJOU, PARIS 8e. TÉL. : ANJ. 17-36. TELEX : 27078 SILIS-PARIS

We have agencies in following countries : Austria • Belgium • Denmark • Finland • Germany
Holland • Ireland • Italy • Japan • Norway • Spain • Sweden • Switzerland



Superior now offers 5 different analyses of stainless tubing for fuel element cladding

Before selecting tubing for fuel element cladding in nuclear reactors, consider the stainless types now offered by Superior. Important characteristics are listed in the table, but there are other important advantages, too. Closer tolerances can be maintained than with such materials as zirconium or columbium and their alloys. Better surface finishes are available. And higher reliability in chemical composition, availability and fabrication into the basic mill forms needed for producing small-diameter tubing is possible.

Superior Specification STC-102 outlines the quality and technical requirements of Nuclear Quality Fuel Element Tubing in these austenitic stainless steels. Write for your copy today. Superior Tube Company, 2027 Germantown Ave., Norristown, Pa.

TYPE	REMARKS
348	1. Good strength at elevated temperature 2. Low neutron absorption characteristics 3. Stabilized against injurious carbide precipitation 4. Most widely used analysis for this purpose
304	1. Most economical of all alloys listed 2. Strength at elevated temperature good, but not as strong as 316, 347 and 348 3. Good for all-around applications 4. Excellent ductility and fabricability
304L	1. Excellent welding characteristics 2. Best ductility, fabricability 3. Less expensive than 316, 347 and 348 4. Lowest strength at elevated temperature of alloys listed
316	1. Best strength at elevated temperature 2. Excellent corrosion resistance in reactor coolants 3. Good fabricability 4. Creep strength best of 300 Series
347	1. Good strength at elevated temperature 2. Neutron absorption characteristics generally higher than those of 348 3. Stabilized against injurious carbide precipitation 4. Less expensive than Type 348

Stainless Steel

Superior Tube

The big name in small tubing

NORRISTOWN, PA.

All analyses .010 in. to ⅜ in. OD—certain analyses in light walls up to 2½ in. OD

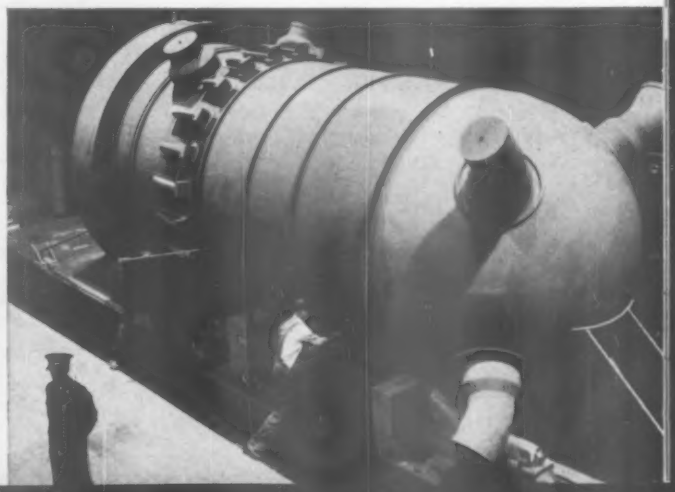
West Coast: Pacific Tube Company, Los Angeles, California • FIRST STEEL TUBE MILL IN THE WEST

This steam generator, being assembled in a C-E shop, is one of ten on order for the Atomic Energy Commission's New Production Reactor, Hanford Works, Richland, Washington. Designed and built by C-E, each generator is 10 feet in diameter, 57 feet long, weighs 170 tons and contains 20 miles of stainless steel tubing. (See below.)

Designed and Built by

Loaded aboard a special, heavy duty flatcar, a completed steam generator begins its trip to Hanford (see photo and caption above). If all ten units are used to generate power, Hanford will be the world's largest nuclear power plant with a capacity of about 700,000 KW.

The reactor vessel for the country's first commercial (PWR) nuclear power plant is shown here prior to its trip to Shippingport. This 250 ton, 8⅜-inch-thick vessel was designed and built by C-E.



The steam generators and reactor vessels pictured here are representative of Combustion's ability to serve the nuclear field in the design and manufacture of heavy nuclear components.

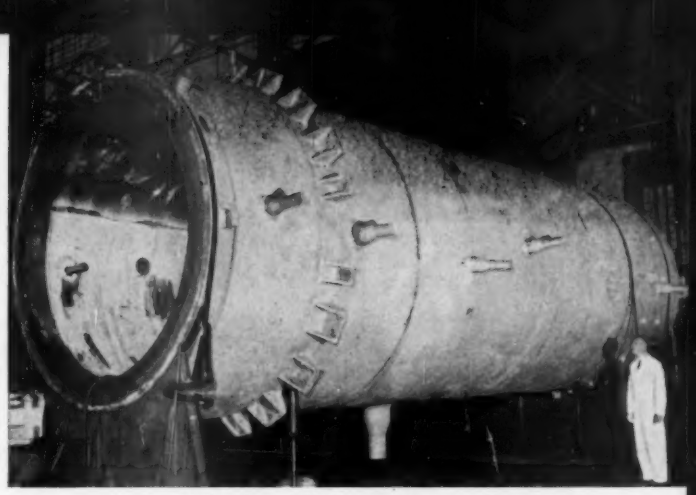
But C-E experience in this area is not limited to the units illustrated. For instance, current C-E work includes the design of the reactor vessel for Italy's first commercial Boiling Water Reactor (SENN); the design and fabrication of the reactor vessel for the 50 emw BWR for the Consumer Power Company's Big Rock Point Plant; the design and fabrication of the reactor vessel for the world's largest PWR, the 375 emw plant of Southern California Edison Company. The "Southern Cal" vessel will weigh-in at about 450 tons, will stand 43 feet high, will be 10¼ inches thick and will have a diameter, over flanges, of about 15 feet.

In addition to this work for the electric utility industry, C-E has been a major component supplier to the U.S. Navy, having designed and built reactor vessels for a number of nuclear powered submarines, the Aircraft Carrier Enterprise, the Cruiser Long Beach, and the Frigate Bainbridge.

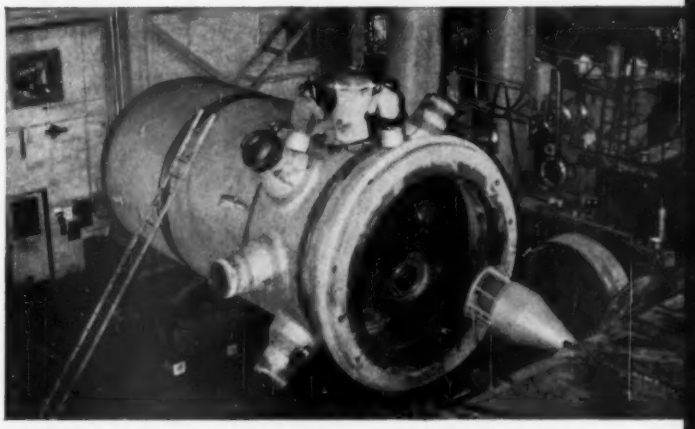
C-E has the personnel, the facilities and the know-how to design and build components of all kinds. It specializes in those which are large, heavy or thick—those which require a high degree of finish—those which are extremely complex—those made of stainless steel or special alloys —or those which must be surgically clean or optically flat.

C-E heavy duty dock loading facilities, adjacent to the plant on the Tennessee River, allow the economical shipment by water of very heavy components (in excess of 400 tons). All coastal points and many inland cities can be reached via the inland waterway system and without clearance restrictions.

For further information, write to your nearest C-E office or to Nuclear Component Sales in Windsor, Conn.



Reactor vessel for Pacific Gas and Electric Company's 50 emw Boiling Water Reactor Plant at Humboldt Bay. This 140 ton vessel is 10 feet in diameter and 42 feet long. It was designed and is being built by C-E.



Hydro caps being welded to the nozzles of the reactor vessel for the 180 emw Pressurized Water Reactor for SELNI (Societa Elettronucleare Italiana) in Italy. This vessel, designed and built by C-E, has a shell thickness of 9⅝-inches and weighs 285 tons.

Combustion

Made entirely of stainless steel, this reactor vessel is part of the Liquid Sodium Cooled, 100 emw, Fast Breeder Reactor system of the Atomic Power Development Associates at Lagoona Beach, Michigan. One of the most complex vessels ever built, it weighs about 380 tons, including its rotating plug. It was designed and built by C-E.

COMBUSTION ENGINEERING C-E

C-323

General offices: Windsor, Connecticut

New York offices: 200 Madison Avenue, New York 16

ALL TYPES OF STEAM GENERATING, FUEL BURNING AND RELATED EQUIPMENT; NUCLEAR REACTORS; PAPER MILL EQUIPMENT; PULVERIZERS; FLASH DRYING SYSTEMS; PRESSURE VESSELS; SOIL PIPE

SAMES

Société Anonyme de Machines Électrostatiques
21, rue Jean Macé B. P. 150 Tél. : 44-77-64
Grenoble, **France.**

ANNOUNCES

the opening of the Office of the U.S. Representative for United States sales of :

HIGH VOLTAGE POWER SUPPLIES

50 kV to 600 kV, 0,2 to 14 ma
Regulation from 3 to 0,001 %
Electrostatic Generator Principle

Used for
ELECTRON OPTICS
X-RAY THERAPY & METALLOGRAPHY
INSULATION & CABLE TESTING

PARTCLE ACCELERATORS FOR NEUTRON GENERATION

150 kV, 300 kV and 600 kV, 0,6 to 2 ma
ion or electron beam currents, constant or pulsed

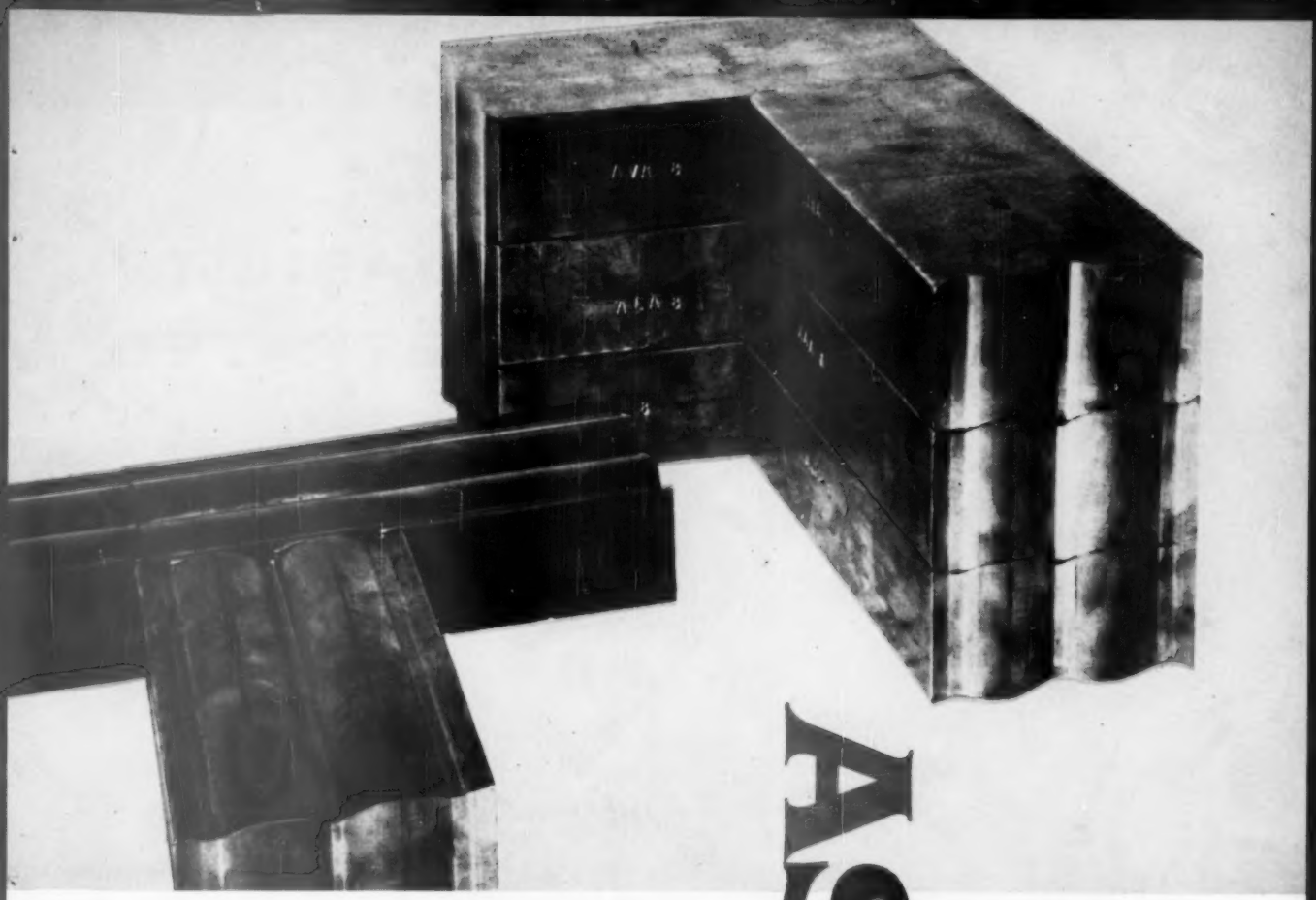
Used for
ACTIVATION ANALYSIS
NUCLEAR RESEARCH
NUCLEAR TEACHING

EUROPEAN SALES AGENTS OF **SAMES** ARE:

Austria : AUSTRONIK, Salzburg
Belgium : GENTRONICS, Brussels
Chinese People's Republic : Cie OLIVIER, Paris
Denmark : DANSK SCIENTA, Copenhagen
Great Britain : MILES HIVOLT LTD, Shoreham by Sea
Italy : SECI, Milan
Netherlands : PROJECTO, Amsterdam
Norway : LEHMKUHL, Oslo
Portugal : A. G. M. E., Lisbon
Spain : CRESA, Barcelona
Sweden : SCIENTA SCANDIA, Gothenburg
Switzerland : OMNIRAY, Zurich
Western Germany : DR. NAMUR, Darmstadt
Bulgaria, Czechoslovakia, Eastern Germany, Hungary, Poland, Rumania, U.R.S.S. : CIFAL, Paris.

For further information in the United States, please write or call : DIgby 4-1286

Office of the U. S. Representative, Room 3701, 30, Broad Street, New-York 4, New-York.



Maximum shield efficiency:

FEDERATED INTERLOCKING* LEAD BRICKS

With Federated's unique interlocking bricks, there's no need to order extra thickness to safeguard against leakage. Because of the unique design of the bricks, any Gamma rays that penetrate the first angle of a Federated interlocking joint will strike an equal or even greater depth of lead than the straight thickness of the wall! Get a full inch of protection for every inch of lead you buy; specify FEDERATED INTERLOCKING BRICKS. Federated also stocks many sizes of lead containers for handling materials with a wide range of radioactive intensities. For information about standard and special shapes of shielding lead, lead castings, lead-filled vessels and containers, write or call: Federated Metals Division, American Smelting and Refining Co., 120 Broadway, N. Y. 5, or your nearest Federated sales office.

*Patent No. 2,970,218

ASARCO

AMERICAN SMELTING AND REFINING COMPANY

FEDERATED METALS DIVISION

Where to call for information:

ALTON, ILLINOIS
Alton: Howard 5-2511
St. Louis: Jackson 4-4040

BALTIMORE, MARYLAND
Orleans 5-2400

BIRMINGHAM, ALA.
Fairfax 2-1802

BOSTON 16, MASS.
Liberty 2-0797

CHICAGO, ILL. (WHITING)
Chicago: Essex 5-5000
Whiting: Whiting 826

CINCINNATI, OHIO
Cherry 1-1678

CLEVELAND, OHIO
Prospect 1-2175

DALLAS, TEXAS
Adams 5-5034

DETROIT 2, MICHIGAN
Trinity 1-5040

EL PASO, TEXAS
(Asarco Mercantile Co.)
3-1852

HOUSTON 29, TEXAS
Orchard 4-7611

LOS ANGELES 23, CALIF.
Angelus 8-4291

MILWAUKEE 10, WIS.
Hilltop 5-7430

MINNEAPOLIS, MINN.
Tuxedo 1-4109

NEWARK, NEW JERSEY
Newark: Mitchell 3-0500
New York: Digby 4-9460

PHILADELPHIA 3, PENNA.
Locust 7-5129

PITTSBURGH 24, PENNA.
Museum 2-2410

PORTLAND 9, OREGON
Capitol 7-1404

ROCHESTER 4, NEW YORK
Locust 5250

ST. LOUIS, MISSOURI
Jackson 4-4040

SALT LAKE CITY 1, UTAH
Empire 4-3601

SAN FRANCISCO 24, CALIF.
Atwater 2-3340

SEATTLE 4, WASHINGTON
Main 3-7160

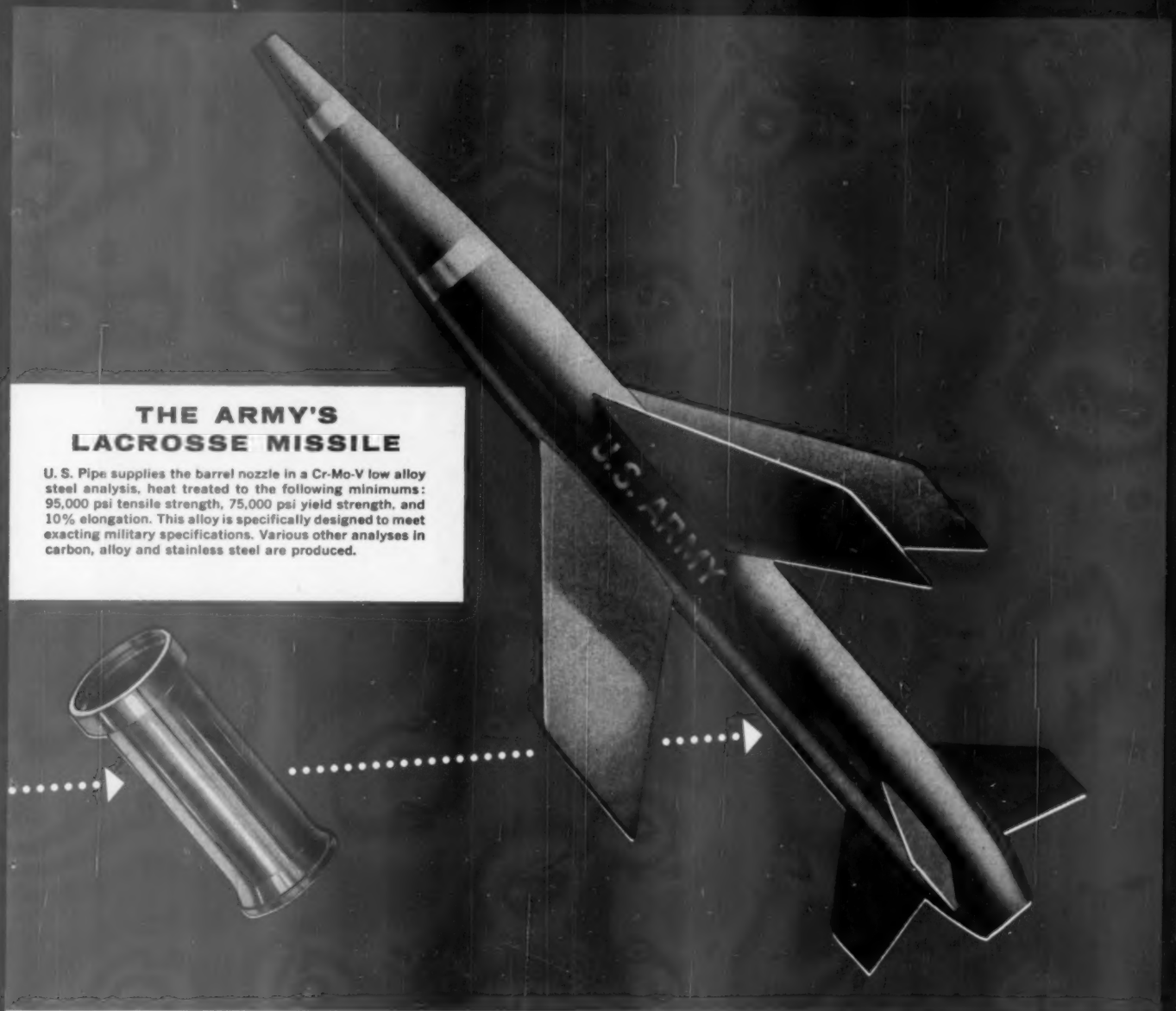
WHITING, IND. (CHICAGO)
Whiting: Whiting 826
Chicago: Essex 5-5000

IN CANADA: Federated Metals Canada, Ltd.
Toronto, Ont., 1110 Birchmount Rd., Scarborough, Phone: Plymouth 73246

Montreal, P.Q., 1400 Norman St., Lachine, Phone: Melrose 7-3591

Q. E. D.
DEPENDABILITY DEMONSTRATED

Now... basic characteristics of Metal Mold Centrifugal Casting contribute to the reliability of new Lacrosse Missile



THE ARMY'S LACROSSE MISSILE

U. S. Pipe supplies the barrel nozzle in a Cr-Mo-V low alloy steel analysis, heat treated to the following minimums: 95,000 psi tensile strength, 75,000 psi yield strength, and 10% elongation. This alloy is specifically designed to meet exacting military specifications. Various other analyses in carbon, alloy and stainless steel are produced.

Centrifugal casting, a direct production approach to quality, is now finding new and increasingly useful applications in rocketry and missile engineering.

U. S. Pipe, for example, supplies the alloy steel barrel nozzles for the Army's Lacrosse Missile as semi-finished, partially hot-forged lengths. These production pieces are being supplied to The Martin Company, Orlando, Florida — prime contractor for the Lacrosse, and to Parish Pressed Steel, Reading, Pennsylvania — subcontractor to The Martin Company. The contractors then finish machine them for assembly in the propulsion units.

Centrifugal casting offers ordnance design engineers several outstanding advantages:

1. **Versatility.** Many different alloy and stainless steel analyses, sizes and contours can be produced starting with a hollow billet.

2. **Dependability.** Years of experience in producing metal mold centrifugal castings assures high quality and reproducibility.

3. **Economy.** Maximum utilization of the *right* material produced with a minimum of processing to achieve overall efficiency.

Can these basic qualities meet the requirements and lower the cost of your material needs? Write today and outline your particular problem.

Size Range & Composition Flexibility
Outside Diameter—6" to 60" • Wall Thickness—⅜" and up
Length—Up to 25'
Types of Steel Cast, Carbon, Alloy and Stainless—all standard AISI and ACI grades.

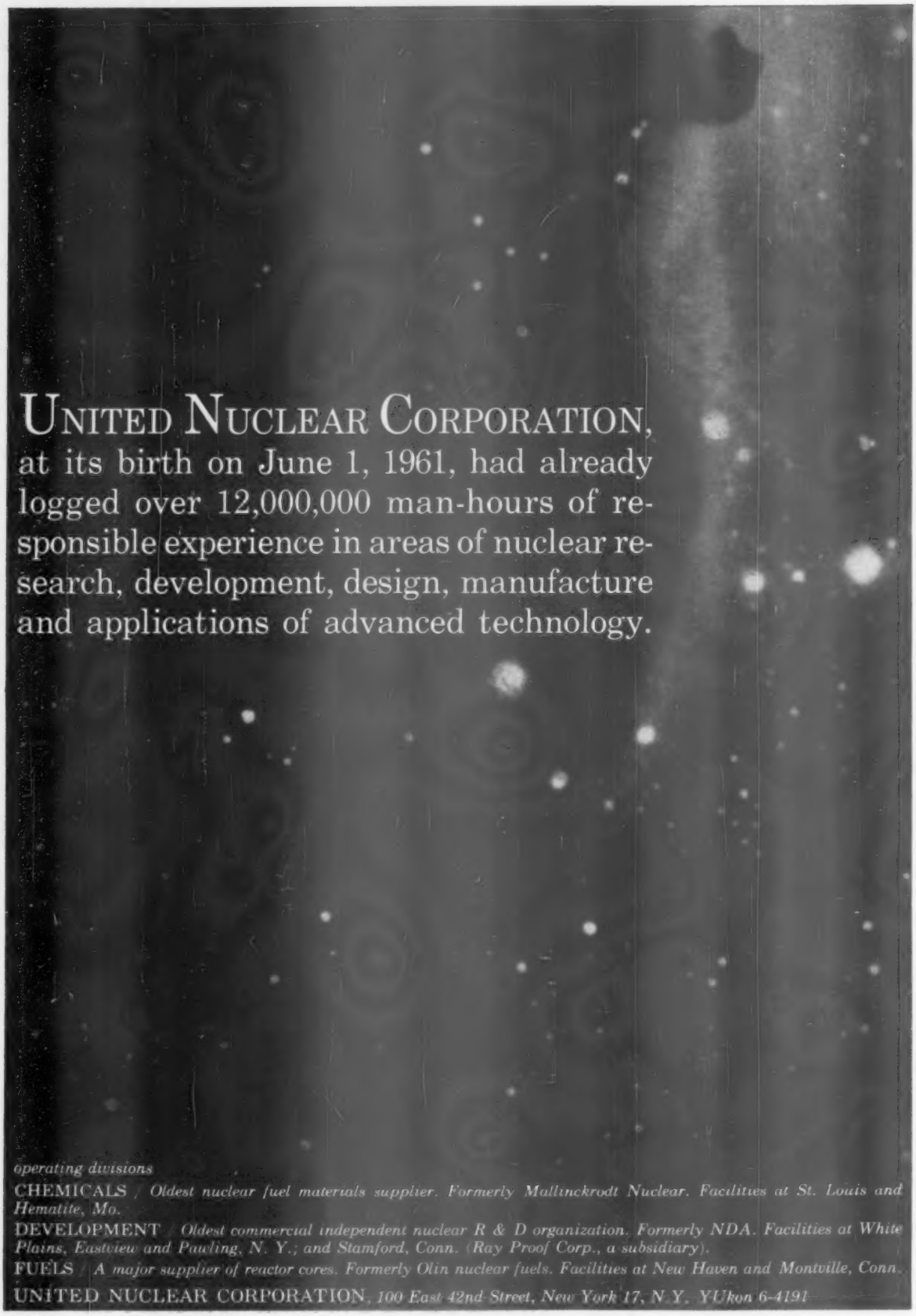
UNITED STATES PIPE & FOUNDRY CO.

Steel and Tubes Division

STEEL & TUBES U.S. PIPE DIVISION

BURLINGTON, NEW JERSEY

SALES OFFICES: BURLINGTON, HARTFORD, BIRMINGHAM, CHICAGO, CLEVELAND, DALLAS, LOS ANGELES, NEW YORK, PITTSBURGH, SAN FRANCISCO


UNITED NUCLEAR CORPORATION,
at its birth on June 1, 1961, had already logged over 12,000,000 man-hours of responsible experience in areas of nuclear research, development, design, manufacture and applications of advanced technology.
operating divisions
CHEMICALS / Oldest nuclear fuel materials supplier. Formerly Mallinckrodt Nuclear. Facilities at St. Louis and Hematite, Mo.
DEVELOPMENT / Oldest commercial independent nuclear R & D organization. Formerly NDA. Facilities at White Plains, Eastview and Pawling, N. Y.; and Stamford, Conn. (Ray Proof Corp., a subsidiary).
FUELS / A major supplier of reactor cores. Formerly Olin nuclear fuels. Facilities at New Haven and Montville, Conn.
UNITED NUCLEAR CORPORATION, 100 East 42nd Street, New York 17, N.Y. YUkon 6-4191

Supreme Court Upholds AEC on Fermi Construction Permit

(The U. S. Supreme Court's Fermi decision (below) highlighted a series of important developments last month on nuclear safety and regulation. AEC released a report of its Board of Investigation on the SL-1 accident (page 22); the Joint Committee on Atomic Energy held four days of hearings on regulation and safety (page 23); and a committee of the Atomic Industrial Forum proposed extensive revisions in AEC's proposed reactor site criteria (page 30).)

The U. S. Supreme Court last month upheld the Fermi fast breeder construction permit and the authority of AEC to have issued it.

Seven justices concurred in the majority opinion; two dissented. The case was the first contested licensing procedure to have been decided by AEC under the 1954 Atomic Energy Act, and was the first atomic-energy case to reach the Supreme Court.

In a landmark decision long anxiously awaited by both the utilities and the manufacturers comprising the civilian nuclear power industry, the high court restored a measure of firm footing to reactor-building groups uncertain of the legal value of an AEC construction permit, and unsure whether the safety of a reactor might have to be demonstrated prior to start of construction—thereby losing 3–4 years during which safety-development work could otherwise be carried on concurrently with construction. And in specifically striking down the "compelling reason" doctrine adduced by the Court of Appeals last June in a decision against AEC now reversed (the doctrine stated that no power reactor may be located near a large city without "compelling reason"), the Supreme Court gave some assurance to utilities that nuclear power plants would not necessarily be forced entirely away from load centers for all time as a matter of law—although in effect the Advisory Committee on Reactor Safeguards is at present effectively keeping power reactors out of cities, at least for the time being, as a function of the state of technology.

Fermi's builder, Power Reactor Development Co., was frankly elated; General Manager Robert Hartwell said the decision was "very satisfactory . . . we're very encouraged . . . I'm confident it will help the industry." Even a spokesman for the "losers" of record—three Detroit-based labor unions—had confided two months ago that win, lose or draw in the Supreme Court, they felt they had accomplished their purpose merely by carrying their fight to the Supreme Court and calling the government's and the public's attention to the problems involved. (Certainly it is true that when AEC issued to Fermi its construction permit almost five years ago there were no public hearings in reactor-licensing cases, legally required or otherwise; there was no AEC Office of Hearing Examiner; there was no requirement that reports of ACRS be published; there was no regulation setting out a step-by-step licensing procedure.)

However this was far from the view of all union leaders. Ben Sigal, the unions' attorney who had carried the fight to AEC for five years, denied that the unions had achieved their objective: "We didn't go into this case for an academic discussion of the law." He said the case did achieve useful results, but he severely criticized the high court's majority opinion for not having given proper weight to a number of points raised in the unions' brief, for remaining silent on the charge that AEC failed to make an adequate hazards study of the site, for alleged errors of fact regarding the history of the case, and for an "extraordinary" statement construing the intent of Congress ("The best we can say about this statement, with all deference," the opinion says, "is that it must have been inadvertent.").

Asked whether the unions would seek to intervene or contest PRDC's application for an operating license when it is filed, Sigal said, "I can't tell you that now; the decision obviously can't be made until all proceedings still to be made are completed. PRDC has asked six more

Conclusion of the Supreme Court Majority Opinion:

"We hold, therefore, that the Court of Appeals erred in setting aside the order of the AEC continuing PRDC's provisional construction permit in effect. We deem it appropriate to add a few words concerning the fears of nuclear disaster which respondents [the unions] so urgently place before us. The respondents' argument is tantamount to an insistence that the Commission cannot be counted on, when the time comes to make a definite safety finding, wholly to exclude the consideration that PRDC will have made an enormous investment. The petitioners [AEC and PRDC] concede that the Commission is absolutely denied any authority to consider this investment when acting upon an application for a license for operation. PRDC has been on notice long since that it proceeds with construction at its own risk, and that all its funds may go for naught. With eyes open, PRDC has willingly accepted that risk, however great. No license to operate may be issued to PRDC until a full hazards report has been filed, until the AEC's Advisory Committee on Reactor Safeguards makes a full investigation and public report on safety to the Commission, until the Commission itself, after notice and hearings at which respondents, if they desire, may be heard, has made the safety-of-operation finding required by Sec. 182a and Reg. 50.35, and until the other requirements of Sec. 185 have been met. It may be that an operating license will never be issued. If one is, that will not be the end of the matter. The respondents may have judicial review. Moreover, the Commission's responsibility for supervision of PRDC continues. For, under Reg. 50.57, 10 CFR 50.57, operation at full power [100,000 kwe] will not be permitted until several steps of gradually increasing operation have been successfully mastered, with a full public hearing at each step, and no further advance permitted without the AEC's being fully satisfied that a step-up will meet the high safety standards imposed by law. This is the multi-step scheme which Congress and the Commission have devised to protect the public health and safety. We hold that the actions of the Commission up to now have been within the Congressional authorization. We cannot assume that the Commission will exceed its powers, or that these many safeguards to protect the public interest will not be fully effective.

"Accordingly, the judgment is reversed and the cause is remanded to the Court of Appeals for further proceedings consistent with this opinion."

months to complete the reactor; it will depend on the facts at that time—I can't forecast now."

A high AEC official took the decision in stride, commenting only, "We still have a continuing, heavy safety responsibility, and will continue to carry it out." He granted that the action "may have a considerable impact" on the industry.

An industry source said the decision "paves the way for Peach Bottom" —the High-Temperature Gas-Cooled Reactor, an advanced developmental reactor to be built near Philadelphia and Baltimore. "Peach Bottom was hung up until this came along, on 'compelling reason' . . . "

Satisfaction was also expressed over the specific mention—thus implying approbation—of the AEC's policy requiring step-by-step licensing review.

The Opinion of the Court. Delivered by Justice William Brennan, the 19-page majority decision is a straightforward report. After stating the issue, it describes (in "rudimentary summary") the Fermi reactor, recites the history of the case, examines in detail the questions of law involved, and reaches a conclusion (*see box page 21*).

'Compelling Reason.' "The position is without merit," the majority opinion held. "The statute and regulations say nothing about 'compelling reasons.' Of course Congress (and the Commission too, for that matter) had the problem of safety uppermost in mind, and of course that problem is most acute when a reactor, potentially dangerous, is located near a large city. But the Commission found reasonable assurance, for present purposes, that the reactor could be safely operated at the proposed location, and that is enough to satisfy the requirements of the law."

The Dissent. Justice William O. Douglas wrote the dissent, and Justice Hugo Black concurred. They based their position on the legislative history of the Atomic Energy Act of 1954 to show that "the finding on 'safety' . . . must be made at the time the construction permit is issued or not at all" and on the view that "after construction is finished . . . when millions have been invested, the momentum is on the side of the applicant not on the side of the public."

PRDC's Plans. The Fermi reactor itself has almost been completed and work is going ahead. Scheduled nonnuclear testing is proving useful ("we just finished heating the sodium in the primary to over 1,000°F, and it gave some thermal-expansion problems we were glad to learn about now"). PRDC now hopes to have a license to start operations by the end of the year. It expected to file 85% of the complete hazards summary report late in June, the last section in July, and at that time will file its application for the operating license. The reactor operators are ready to take their examinations soon.

PRDC has been meeting every two or three months for the last two years with ACRS's fast-reactor subcommittee, so ACRS has a close acquaintance with the reactor and with what PRDC has been doing.

SL-1 Inquiry Report: AEC Still in Doubt on Accident Cause

With "substantial doubt" remaining on the cause of the SL-1 explosion five months after the accident (NU, Feb. '61, 17), AEC released last month its best guess as to what happened, pending eventual dismantling of the core in a hunt for more conclusive evidence. Last month's report, prepared by AEC's Board of Investigation, offered little that was new on the probable cause: the board still feels that an "unusually rapid and extensive motion of the central control rod" probably caused the nuclear excursion that led to an explosion.

However, the board discussed at length the pre-explosion problems at SL-1 (including a history of sticking control rods); steps that might have prevented the accident; and the fixing of responsibility (the board said responsibility would have to be shared at several levels, from SL-1 operator Combustion Engineering to AEC General Manager A. R. Luedecke).

Meanwhile, at hearings of the Joint Committee on Atomic Energy on nuclear safety and regulation (*see page 23*), AEC Commissioner Robert Wilson said AEC had learned seven "important things" from the accident:

1. Reactor designers should avoid reactors capable of going critical on withdrawal of one control rod.

2. A reactor experiencing control or other major operating difficulties should be shut down "until effective remedial steps" have been taken; also, the decision to continue operating SL-1 despite rod-sticking and loss-of-boron problems was made at too low a level within AEC and without proper review.

3. There should be detailed procedures for conducting reactor maintenance, etc., preferably with supervision by a technically trained individual at all times.

4. There should have been an operator in the control room at SL-1 while the control-rod drive mechanisms were being connected.

5. Every reactor—licensed or AEC-operated—should have periodic safety review by an independent group (this is done for licensed reactors by AEC's licensing and inspection staffs).

6. Responsibility for health and safety was not clearly defined within AEC.

7. The one positive or reassuring "lesson": SL-1's housing, though not designed for tight containment, was "very effective" in containing radioactivity.

Changes at AEC?

As a result of the SL-1 experience, AEC officials feel it probable that two steps will be taken to render surveillance of AEC-operated reactors as strict as it has always been for licensed reactors. Prior to SL-1, AEC had already established "parallel procedures" for government-owned reactors operated by public utilities and for NS *Savannah;* that is, virtually every safety-review step required for licensed reactors is now required for these reactors. However, a much less stringent attitude has prevailed for reactors operated by AEC itself.

Therefore, some AEC officials expect the Commission to strengthen the lines of communication and authority between headquarters and the operators of reactors at AEC sites and to create an inspection system comparable to that for licensed and "parallel procedure" reactors.

The board of investigation, headed by Inspection Division Director Curtis Nelson, made a specific point of the less stringent attitude toward AEC-operated reactors:

"Evaluation of the hazards of specific reactor designs or operational programs by the staff of the Division of Licensing and Regulation (DLR) is not required, except as the director of the operating division may specifically request. For new facilities, the operating division director usually requests review by DLR before operation, although this is not required and there is no subsequent follow-up at the initiative of DLR. It is similarly not required that the division director get DLR review of later changes in a facility. This later view is often requested, but not as regularly as for new facilities. Later review was not requested for SL-1. Inspection of reactor operations by the Division of Compliance is not required, but may be requested. Safety review and inspection by the AEC staff are required for all licensed reactors and for certain AEC-owned reactors [second round, plus *Savannah*].

AEC Against 3-Man Board; Drop Mandatory Hearings?

Administration opposition to a 3-man "Atomic Safety and Licensing Board" at AEC appears to have blocked any chance of its adoption this year, despite a generally favorable reaction to the proposal by industry. Unyielding opposition to the proposed board—by both AEC and President Kennedy's regulatory advisor, James Landis—emerged during hearings of the Joint Committee on Atomic Energy last month on nuclear regulation and safety.

The 3-man Board had been proposed earlier this year by the staff and consultants to JCAE (NU, March '61, 26), with a view to improving AEC's safety-review-hearing process by substituting two technical and one administrative expert for the hearing examiner. The board would also be a step in the direction of eventual separation of AEC's regulatory and promotional responsibilities. Meanwhile, AEC had reorganized itself internally to separate the promotional and regulatory functions at the staff level.

Industry's majority sentiment on these two types of reorganization, solicited by JCAE Staff Director James Ramey in March, could be summed up: 1. AEC's internal reorganization was desirable; but 2. the substitution of the 3-man board for a single, non-technical hearing examiner would also make sense as an additional step. The board would make final decisions in hearing cases, but leave rule- and policy-making to AEC for the time being.

However, Landis and Commissioner Loren Olson, speaking for AEC, said it was too early to take final licensing authority away from the same commission responsible for promotion and development of nuclear technology.

"Bifurcation of power has not developed in the atomic energy field," Landis told JCAE, "and we may come to a resolution too quickly. I would hate to follow theory when the practicalities aren't such as would demand it."

Olson said that creation of a director of regulation, reporting directly to the 5-man Commission, made any additional change unnecessary. He said he did not believe that AEC's promotional responsibilities "prejudice the proper discharge of its regulatory responsibilities." However, he indicated he would accept an idea put forth in jest by Ramey: that two technical assistants be assigned to each AEC hearing examiner to give technical sophistication to the hearing process.

Mandatory Hearings

In contrast with the disagreement over further regulatory reorganization, there was virtually complete agreement at the hearings on the need for modifying the mandatory-hearing procedure for reactor-license applications. Olson and fellow-Commissioner John Graham reminded JCAE that the mandatory-hearing requirement had been forced on AEC by JCAE in 1957, after the squabble over AEC's issuance of a construction permit on the Fermi reactor (see page 27).

The concensus appeared to be: that only one full-fledged public hearing was required, preferably at the site-selection, pre-construction stage; and that, in many uncontested cases, public hearings could be dispensed with completely in favor of publication of all pertinent hazard analyses. The door would be left open for an intervention and scheduling of a hearing when sought by interested parties.

W. F. Kennedy, counsel for General Electric's Atomic Products div., said there was a "general industry conviction that the AEC decision procedures have become too cumbersome, too time-consuming and too expensive."

Olson disclosed that AEC was trying an experiment that, if it is successful, could eventually be used as a substitute for some of the formal hearings now mandatory. This was AEC's scheduling of a public meeting June 19 at Pleasanton, Calif., to report on the Vallecitos Superheat Reactor proposed for construction by GE (NU, Apr '61, 26). Olson described this as an "experiment" when witnesses at the JCAE hearings warned that AEC officials might be putting themselves on record as to its safety before the formal construction-permit hearing June 30.

AEC had said in its announcement of the meeting that its purpose was "to give members of the public who live in the area where the reactor would be located an opportunity to ask questions of AEC regulatory personnel." The meeting also will enable members of the Commission's regulatory staff to describe AEC regulatory procedures and review safety considerations involved in the proposed reactor."

Participating AEC officials were to include: Robert Lowenstein, acting director of AEC's Licensing and Regulation div.; Clifford K. Beck, assistant director for Facilities Licensing in the same division; and Merson Booth, a reactor engineer.

Uranium Price Cuts Hailed; AEC Studies Sale

Effective the first of this month, AEC has reduced its prices for enriched uranium by an average of 25–30%, thereby recognizing the 33% reduction in AEC's average costs for U concentrate (from $12/lb to $8) since the previous prices were established in 1954. The lower prices were immediately hailed as a significant contribution to cheaper nuclear power, despite AEC's companion action increasing the use charge from 4% to 4.75% and AEC's disclosure that it was considering the possibility of outright sale to U. S. users of enriched U. A change in the 1954 Atomic Energy Act would be required to permit private ownership.

For private utilities, a switch from leasing to purchase of U from AEC would increase the new use, or inventory, charge from 4.75% to 11–12%, cancelling the price reductions. However, nuclear-power officials were saying last month that they doubted that leasing would be abandoned in the foreseeable future. Their views seemed to be based on the feeling that the government would hardly take such a negatively-economic step while nuclear power was still so developmental and that, even if sale were authorized, AEC would continue a lease option for many years.

Reactor manufacturers were estimating that the price reductions lowered operating costs for large reactors 0.3–0.5 mills/kwh, depending on size and type; General Electric estimated that annual savings on a 300-Mwe, direct-cycle boiling-water reactor would be about $500,000/yr, or $10-million over 20 years. Depleted U prices were also reduced by AEC.

EXAMPLES OF BASE CHARGES FOR ENRICHED AND DEPLETED URANIUM AS URANIUM HEXAFLUORIDE

U-235 Assay in Wt %	New Charges $/kg of Contained U (Official Base Charges)	New Charges $/gm of Contained U-235	Previous Charges $/gm of Contained U-235	% Reduction
Enriched U				
90	12,285.00	13.65	17.07	20
20	2,547.00	12.74	16.12	21
10	1,195.50	11.95	15.29	22
5	535.50	10.71	13.96	23
3	281.20	9.37	12.52	25
2	160.80	8.00	11.00	27
1.5	102.60	6.84	9.70	29
1.0	49.90	4.99	7.58	34
Depleted U				
0.7*	22.60	3.23	5.45	41
0.6	14.80	2.47	4.48	45
0.5	8.05	1.61	3.33	51
0.4	3.00	0.75	2.04	63

If a user specifies a U-235 assay between 0.4 and 0.22 wt %, the charge will be $3/kg of contained uranium. However, if the U-235 assay is not specified by the user, AEC will supply uranium having a U-235 assay to be determined by AEC in the range below 0.4% and will charge $2.50/kg of U.
*Natural U is 0.7115% U-235.

Euratom Optimistic on Power, Seen Ready to Stand on Own

High optimism about nuclear power in the Euratom Community, coupled with an increasingly strong feeling on the part of industry in the six nations that it no longer needs to lean on U. S. technical and financial aid, marked the month on the Euratom front.

An "economic nuclear breakthrough" was forecast by Euratom Commissioner Paul Hubert de Groote. Taken together with the annual report of the six-nation community, de Groote's optimism betokens a real renewal of faith in the rapid growth of nuclear power in western Europe (*see box*).

Meanwhile, another member of the Euratom Commission, Emanuel Sassen, was expressing high hopes for issuance by July 1 of the second-round U. S.-Euratom power-reactor invitation. He said the second round could probably cover not only KBWP, the Stuttgart group, and SENA, the Franco-Belgian group, but also BEWAG, the West Berlin utility, and the Dutch SEP project, now again under active consideration. But while Euratom was officially hopeful and sanguine about the joint program, privately many serious doubts were expressed about it and the need for it. The doubts themselves indicated how much Euratom had gained in confidence during the last two years in its ability to mount a nuclear power program by itself.

'Nuclear Breakthrough'

Now in its fourth year, Euratom is gearing its plans for the economic nuclear breakthrough: the arrival of economically competitive nuclear power. Of it, de Groote said, "Our view is that . . . in Europe [it] will come in 1965 . . . Euratom's hypothesis is that nuclear power will capture half of the new energy market between 1965 and 1970, and two-thirds between 1970 and 1980. If this actually happens, it may mean that nuclear power plants producing a total of some 40,000 Mwe will be installed by 1980. If, contrary to our hopes, nuclear power is not put on a competitive footing until 1970, the nuclear capacity required in 1980 would still amount to some 25,000 Mwe." (These numbers represent not Euratom plans, but Euratom estimates of the probable result of normal competition, it was emphasized.)

Joint Program Obstacles

Stumbling-blocks in the path of the second round of U. S.-Euratom partnership on nuclear power include the "Buy American" clause, long a source of discord, on which a "compromise" has been arranged that does not alter the fundamental requirement; the question of sale or lease of U. S. enriched uranium (Euratom had reversed its original position and now prefers leasing to outright purchase, but Euratom staff members now find AEC unwilling to negotiate lease contracts); imposition of U. S. AEC patent policies; and—perhaps most irritating of all to Euratom—the fact that the U. S. has still to enact legislation enabling fulfillment of last summer's amendments to the U. S.-Euratom agreement, providing 9 kg of plutonium for research.

The Euratom annual report says the Euratom Supply Agency "hopes to improve the conditions of supply of fissionable materials from third countries," but with AEC's apparent reluctance to lease, this would have to be done with the Agency acting as middleman, arranging lease terms with reactor operators but itself financing purchase from the U. S.

There is a strong current opinion in Euratom circles that if the proposal to use research funds to help reactor projects (NU, June '61, 25) gets past the Research Advisory Committee and the Ministerial Council, Euratom should concentrate on this and "let sleeping dogs lie" as regards the second round of the joint program—counting on nuclear power being commercial by 1970, as de Groote foresees it will be. Many accordingly hope that the U. S. will allow the invitation to drop, and will amend the U. S.-Euratom agreement to liberate the joint research program from its compulsory link with reactor types to be installed under the program (pressurized and boiling water and organic reactors, approved for the joint power program).

U. S. Mission View

The U. S. Mission to Euratom hopes the second-round invitation may be useful to SENA and KBWP. The obvious fear of both sides is that the invitation may founder like the first (NU, Nov. '59, 21).

Euratom utilities contemplating building U. S.-type reactors are now felt to be in a position to go it alone without submission to the joint program, which involves making available operating information. The sales point in favor of the program is the cast-iron guarantee of 20 years' fuel supply, 10 years' plutonium buyback, and facilities for reprocessing. It's argued that this is an insurance policy costing only the supply of operating information—which would probably have to be given away anyway if the utility applies for a Euratom subsidy. However European companies still strongly resent the enforced application of U. S. AEC patent policies.

Obviously Euratom utilities will have to weigh the prospects of European fuel fabrication and reprocessing, and the extent of Euratom subsidy offers (which still need approval of the Ministers' Council), and the obligations that these entail before deciding whether this is sufficient to justify dispensing with U. S. guarantees and the experience behind them.

Indications are that Euratom, for its part, is preparing to urge the attractions of nuclear power, mentioning specifically the fuel supply liberated from political transport interruptions (as in the Suez crisis). The important objective for Euratom now is a rapid further development of the European nuclear manufacturing industry including fuel-element fabrication.

In a move to speed development—seen as the first direct competitive challenge to the U. S., especially on small reactors—Euratom signed a bilateral last month (its fourth) with Brazil. It covers almost all types of peaceful nuclear work.

Growth of Euratom Capacity

Projects already underway or planned in the six Euratom countries will account for 1,800 Mwe installed nuclear generating capacity by 1965—almost 2,200 Mwe when maximum design potential of each reactor concerned has been realized by improved cores. The annual additions, with cumulative subtotals:

By end-1960		
G-1, G-2, G-3 (GCRs)	Marcoule	65 Mwe
RWE's BWR	Kahl	15
		80
By end-1961		
BR-3 (PWR)	Mol	12
EDF-1 (GCR)	Chinon	68
		160
By end-1962		
EDF-2 (GCR)	Chinon	170
SIMEA (GCR)	Latina	200
		530
By end-1963		
SENN (BWR)	Garigliano	150
AVR pebble-bed	Jülich	15
		695
By end-1964		
SELNI (PWR)	Trino Vercellese	165
		860
By end-1965		
EDF-3 (GCR)	Chinon	300
SENA (PWR)	Givet	242
EL-4 (D_2O)	Morlaix	100
KBWP (OMR)	Obrigheim	150
BEWAG (PWR)	W. Berlin	150
		1,802

Kennedy Sets Nuclear-Rocket Development as National Goal

Several days before it took office on Jan. 20, the Kennedy Administration released a study of the U. S. space program which aroused real fears that the nuclear-rocket program might be downgraded (NU, Apr '61, 54). These fears were amplified in early April when it was learned that the White House had formed an ad hoc committee to review the nuclear-rocket program (NU, May '61, 22).

Last month, President Kennedy, himself, completely dispelled the anxiety of these recent months by singling out the nuclear rocket as one of four areas of space activity which he felt should be speeded up. In an appearance before a joint session of Congress (unprecedented in mid-Congressional session), the President disclosed two significant policy steps on the nuclear rocket: 1. he announced restoration of $30.5-million in AEC and NASA budgets for fiscal 1962—funds which the Budget Bureau had tentatively refused to approve earlier this year; and 2. he gave his personal, official endorsement to the nuclear-rocket program, thus establishing development of nuclear rockets as a national goal.

"This [program]," he said, "gives promise of some day providing a means for even more exciting and ambitious exploration of space [than liquid and solid chemical rockets], perhaps beyond the moon, perhaps to the very end of the solar system itself."

The reaction to the President's declaration and to his restoration of fiscal '62 funds (subject to appropriation by Congress) was one of jubilance—at Los Alamos Scientific Laboratory, where the rocket reactor is under development; in industry, where the nuclear-rocket program has long had some avid supporters, for both economic and patriotic reasons; at AEC and NASA, where the President's support means much in future fights for program funds; and in Congress, where much crucial and tenacious "spadework," both publicized and unpublicized, has been done since January to persuade the White House to recognize the nuclear-rocket's importance to the U. S. space posture. A Los Alamos official most accurately assessed the White House development: "The situation has changed in six months from having to fight to hold what we had, to the situation today, which is everything we asked."

The bulk of the President's new request will go into engine development—funds to support engine research-development and to build test facilities for nuclear engines.

Aerojet, Westinghouse Win Major Nerva Roles

Aerojet General Corp. was selected by AEC and NASA last month, subject to negotiation of a contract, to begin development of the first nuclear-rocket engine—Project Nerva (Nuclear Engine for Rocket Vehicle Application). In an imaginative move accompanying AGC's selection as prime contractor, AEC and NASA designated Westinghouse Astronuclear Laboratory subcontractor on nuclear development. "Assuming successful contract negotiations," a government official explained, "Westinghouse would certainly handle the reactor end [of engine development]." The initial AEC–NASA contracts with the AGC–Westinghouse team will run for six months and will include: design of the Nerva engine, support of the Kiwi-B reactor-experiment program to be conducted by Los Alamos Scientific Laboratory at Jackass Flats, Nev. (see page 32), preparation of development and cost schedules to meet flight-test target dates, and some research and development.

Expected cost of the Phase I, six-month contract is about $2-million. However, the entire Nerva program is expected to cost several hundred million dollars and AGC–Westinghouse will probably be the key participants.

Anderson Quietly Effective

If there was a single personality in Washington most effective in bringing about White House endorsement for the nuclear-rocket program it was Sen. Clinton P. Anderson (D.-N. Mex.), former chairman of the Joint Committee on Atomic Energy (still a JCAE member) and a member of the Senate Aeronautical and Space Sciences Committee. Anderson had said in February that he intended to dedicate himself totally to assuring the success of the nuclear-rocket development program.

Anderson

Since his own party took over the Administration five months ago, he has worked tirelessly, quietly and effectively on acceleration of nuclear-rocket development. It is probable that Anderson's direct contacts with the President, Vice-President Lyndon Johnson (chairman of the National Space Council) and Presidential Science Adviser Jerome B. Wiesner were more responsible than anything else for the White House action last month. As the President announced his decision to accelerate the nuclear-rocket program, Anderson commented:

"I think that is excellent. I do believe this [nuclear rocket] has enormous possibilities. We could go faster if we took some chances but I think we're making very good progress—I think the engine will be ready by the time we get the vehicle [Saturn] ready." [The first nuclear rockets are to be boosted by the Saturn (*see page 32*)]."

Some lesser, but still meaningful, measure of credit for the high-level recognition of the nuclear rocket must go to Rep. Overton Brooks (D.-La.) and the House Science and Astronautics Committee of which he is chairman. The Brooks Committee has emerged this year as a particularly vocal proponent of nuclear rocketry—calling special hearings on the Rover program (NU, Apr. '61, 24) and, last month, restoring $23.5-million of NASA nuclear-rocket funds even before the President's statement of restoration on the same funds.

In a report on the Rover hearings in early April, the Brooks Committee committed itself wholly to the nuclear-rocket program with these five recommendations: 1. NASA should accelerate engine development by selecting both engine and vehicle contractors "at the earliest practicable date"; 2. The AEC/NASA Space Nuclear Propulsion Office, headed by Nuclear-Rocket Manager Harold B. Finger, "should be provided with sufficient authority effectively to direct the progress" of the program; 3. Los Alamos should concentrate on advanced and higher power reactors than those now contemplated, leaving engineering tasks to the engine-contractor team when it gets into engine development; 4. NASA should be prepared to increase funding for engine-testing facilities at Jackass Flats, Nev. [proposed site of the National Nuclear Rocket Development Center]; and 5. "The highest national priority . . . should be assigned to the nuclear-rocket-development program."

1962 Funding

With restoration of $30.5-million in the fiscal '62 requests of NASA and AEC, the two agencies are seeking a total of $89.5-million for the nuclear rocket. A breakdown: AEC ($49-million), $42-million in operating funds for reactor development (*see page 32*), procurement of engine hardware and safety studies, and $7-million for construction of reactor-test facilities at Jackass Flats; NASA ($40.5-million), $25.5-million for research-development on an engine and $15-million for construction of engine-test facilities at Jackass Flats.

Seaborg's Informality, Sharing of Power Mark First Months

One-man rule at the Atomic Energy Commission has been suspended indefinitely. The new order: strong five-way group decisional processes —in unmistakable affirmation of an equal vote for each of the five commissioners.

This word comes straight from the man who could most easily swing the pendulum in the other direction—new AEC Chairman Glenn T. Seaborg. He favors full commissioner participation when it gets down to making the big decisions on the peaceful and military atom.

Neither will there be line responsibility delegated to any one commissioner for any major item that comes before AEC, Seaborg said in an interview. "We'll work as a Commission and act on Commission business as a group," he says. "There will never be a delegation of responsibility by me to individual commissioners."

Scientists and Lawyers

One noticeable characteristic begins to emerge as the profile of the "new" Commission under Seaborg assumes tone and color at the age of five months. In Commission deliberations, the influence of three scientifically trained commissioners (Seaborg, Leland J. Haworth, Robert E. Wilson) sitting at the same table with two lawyers (Loren K. Olson, John S. Graham) has begun to show.

The scientific as distinguished from the legal approach to nuclear matters is difficult to nail down, in terms of practical difference. But basically it is bringing more concern for research-development programs and related facilities. Among other things, this means that in terms of future budgets, increases in physical research-development programs will be greater than elsewhere in the AEC budget.

The two new Commissioners, Seaborg and Haworth, want to see the level of physical research expenditure, currently at about $180-million annually, eventually equal that of the other major AEC programs, or about $500-million/yr. With the other programs—such as reactor development, weapons, raw materials, etc., essentially frozen—a significant increase in physical research could boost the AEC budget to more than $3-billion for the first time in its history; this could come in fiscal '63. Also, Seaborg would like to see a 50–100% increase in funds for the Isotope Development Program.

Seaborg and Haworth are devoted to the principle of federal support for scientific research. This is the area where hassles could erupt within this Commission; however, there are no traces yet of conflict along political lines. It will be as scientists—rather than as politicians—that Seaborg and Haworth recommend bigger science programs. It will be as conservative lawyers, rather than as a Democrat or Republican, respectively, that Graham and Olson might take a cautious view of such programs. There have been no political schisms in the present Commission up to now, and under Seaborg none are likely.

A Relaxed Commission

A significant part of the Commission's present complexion can be traced back to Seaborg's own youthful and friendly personality. At the age of 48, Seaborg has had more scientific honors, including a Nobel prize, bestowed on him than perhaps any living practitioner of pure reason. Yet, the able scientist, for all his wisdom, is not pompous. The other Commissioners like their new chairman.

They like Seaborg's fair-minded policy of finding a common ground in reaching Commission decisions. The present order is contrasted by insiders to that of the previous Commission, under John A. McCone, in which the chairman would enter a meeting, toss out his decisions, and with them proceed "to chase the other commissioners into a hole."

Graham, Olson, and Wilson appreciate Seaborg's turning to them on matters on which their past experience qualifies them to give advice. They enjoy the "freer" Commission meetings and the "pleasant and level-headed" knack of Seaborg in presiding over them. So much so that the sessions always overshoot their allotted time. The once-daily morning meetings have now been cut down to Monday, Wednesday and Friday—to make more room on the commissioners' loaded schedules.

At the same time, significant dents have been made in a long-hanging workload, such as last month's approval of price reductions for enriched-uranium (*page 23*).

Wilson Welcomes Scientists

Commissioner Wilson is glad to see the impressive scientific ability of Seaborg and Haworth (for 12 years director of Brookhaven National Laboratory) added to the Commission. Wilson worked primarily in the area of reactor development in the last months of the former Commission. "I'm very much relieved to get out from under some of the scientific load," Wilson says.

Wilson believes he is a better businessman than technician. His favorite AEC program is the industrial development and participation program, where AEC seeks to attract industry to nuclear activities. He modestly claims his knowledge of science is "about 40 years outdated."

Wilson smiles his relief "not to get some of those we thought might be picked" for the positions filled by Seaborg and Haworth.

Seaborg's Influence

The question of how much Seaborg would influence broad policy at the White House is getting answered. President Kennedy calls on Seaborg frequently. He sits in on some but not all Cabinet and Security Council meetings: "I go to those where the relevance to the Commission is there."

With the White House staff, Seaborg works primarily with Presidential Science Advisor Jerome B. Wiesner. Depending on the area, Seaborg may deal with McGeorge Bundy, special

Canadian health agency clears irradiated potatoes

Canada's Directorate of Food and Drug has approved irradiated potatoes for human consumption, officials of Atomic Energy of Canada, Ltd., disclosed last month. The action is believed to be the first health clearance for an irradiated food outside of the Soviet Union, where irradiated potatoes have already been marketed (NU, June '61, 23). Despite years of wholesomeness and other studies, no irradiated food has been approved in the U. S.; however, the Army Quartermaster Corps and the Army Surgeon General's Office are reported nearing submission of data on irradiated bacon to the Food and Drug Administration for approval.

Canada's AECL will build a mobile irradiator this summer for experimental field irradiation of potatoes in four provinces.

NEW AEC AT WORK includes (left to right) Commissioners Loren K. Olson, John S. Graham, Glenn T. Seaborg, chairman, Robert E. Wilson and Leland J. Haworth.

assistant for international security affairs, or with Kennedy trouble shooters Fred Dutton and Ralph Dungan on a broad swath of relations with foreign nations, appointments within the Administration, and various other matters. Haworth, a good friend of Wiesner's, also has excellent rapport with the White House inner circle. Haworth's views are sought when the Administration wants to initiate scientific projects. Seaborg is also a member of the Committee of Principals, the government's primary advisory group for the Geneva test-ban talks.

Sessions of these major committees are also attended by Seaborg: President's Science Advisory Committee, Federal Council of Science and Technology, Federal Radiation Council and the National Aeronautical and Space Council.

The AEC chairman is serious about the task assigned to him as the New Frontier's No. 1 man for atomic matters. President Kennedy wants to turn nuclear technology toward broad national economic benefits and goals, perhaps out of the impression that more can be gotten out of the atom for the large number of dollars being put in. It was in this vein that Seaborg recently suggested that AEC's national laboratories be given assignments in such public-interest areas as desalinization of water.

Seaborg and JCAE

Seaborg is getting on well, as a whole, with the Joint Committee on Atomic Energy. "I enjoy my appearances before the Joint Committee; they're a lot of fun," he says.

He has demonstrated on Capitol Hill that his justly-earned fame as a "scientist-administrator" can easily make the switch to the "scientist-politician." He has not faced the necessity of choosing between one of two extremes on a major political issue thus far. He is aware, however, that scientists do not remain leaders very long by backing off from the hard political decisions. He will make them when the time arrives.

Recently he broke up a building moment of tension at JCAE with a priceless quip. It came as he was requesting authorization of $95-million for the Hanford New Production Reactor (NPR) generators. Objections to the request came flying. "Would you be willing to gamble $95-million of your own money for this?"

"That question I'm sure I haven't the powers even to comprehend," Seaborg said. The entire hearing room disintegrated in peals of laughter.

Staff-Commision Relations

There were serious staff morale problems under the previous Commission. The staff, under General Manager A. R. Luedecke, often felt its interests and best technical judgment were sold short by Commission decisions. The staff-Commission feud at times held back the necessary spade work without which important projects, particularly in the reactor development field, could not move ahead.

The relations between the staff and this Commission are good and, with time, should get even better. Seaborg is "Glenn" to a good many within AEC. He consults freely with the staff. He also has worked with a goodly number of current staffers and family friendships exist with some.

There was staff resistance to the recent re-location of AEC's regulatory-safety inspection arm from the general manager's direction. There will be further internal reorganization of the headquarters staff and field-office activities. But it will not be on grounds that the present Commission wants to set itself above the staff, if staff complaints are heard.

Haworth, particularly, would like to see more direct administrative liaison between Washington headquarters and the national labs. Effective communication and management control over projects is hampered, according to Haworth, under the present organizational set-up. Currently, an AEC area operations office—and perhaps additional field offices—passes the word between the labs and Washington. The Haworth claim is that from the labs the administrative chain flips down to the area operations office and then comes back up to the Commission, and vice versa.

The SL-1 accident of last January may be leading to another type of reorganization. Doubts remain at AEC as to whether the accident would have happened, had not the complexity of the management mixture of Army, Reactor Development div., Idaho Operations Office and operating-contractor over the reactor's operation complicated effective safety-management authority. Future delving into the possible modification of the AEC's organization will be oriented to eliminate the likelihood of recurrence of such accidents.

Commissioners on Business

The recent Seaborg policy statement recommending moves ahead in reactor construction (NU, June '61, 17), and possible expansion of AEC budgets to a $3-billion-plus level mean a definite pick-up in nuclear business. Most commissioners predict a better lot for the nuclear industry than it has yet seen.

Commissioner Wilson believes that certain sectors of the nuclear industry would do well, however, to change their views on doing business with AEC. "When industry is ready to step in and take certain risks, there'll be plenty of atomic business," Wilson says.

"We want to encourage a free nuclear enterprise to come," says Wilson, "but we are not going to let industry in without their taking some risk." Wilson says there is too much unfounded criticism of AEC by business when the latter doesn't get guaranteed profits.

Neither Seaborg nor Wilson see the need for federal construction of full scale power reactors if Southern California Edison (SCE) paves the way for private utilities in building commercial-sized nuclear powerplants. Seaborg stands by his recent policy statement calling for a government nuclear power construction program. However, Seaborg is for trying financial incentives such as capital grants before beginning federal construction of plants. In any case, he says, there must be participation in actual plant construction by industry.

REACTOR NEWS

P&W TO BUILD LITHIUM REACTOR FOR AEC

Pratt & Whitney will build a $13.2-million lithium-cooled reactor experiment for AEC under the advanced materials research program that is all that's left of the recently cancelled Aircraft Nuclear Propulsion program. Under the AEC contract, P&W will "perform the necessary research and development, engineering design, fabrication and test-operation of a high-performance, liquid-metal-cooled, compact reactor experiment to include the reactor heat rejection system and test facility for a variety of applications. The design of this reactor experiment is to be sufficiently flexible to facilitate investigation of various fuel elements, moderators, reflectors, other materials and control rods." P&W's principal contribution in ANP was a molten-lithium-cooled, niobium-contained primary system driving a Nak secondary (intermediate) loop; AEC is interested in adapting this approach for civilian applications (NU, April '61, 23).

PM-1 FLOWN TO AF SITE IN WYOMING

A nuclear power plant sprouted wings last month, as Martin Co., its builder, put it. Nine of the 16 15-ton packages constituting the 1-Mwe (plus 7-million Btu/hr steam for space-heating) package-power reactor, PM-1 (Portable Medium-power No. 1) were flown by C-130A Air Force Troop Carrier Wing planes from Martin's plant airport outside Baltimore 1700 mi to Ellsworth Air Force Base, Rapid City, S. D. From there they will be trucked to an Air Defense Command radar site atop 6650-ft Warren Peak, 7 mi from Sundance, Wyo., which the reactor will supply with electricity and heat. The remaining seven packages are to be delivered in July. Only three months are scheduled to interconnect the packages (they have already been test-connected and -operated at Martin), and the plant is to start supplying power to the base this fall. First nuclear power plant to serve an operational Air Force station, PM-1 will be manned by 17 airmen, two Army and two Navy men under an AF officer.

DAIRYLAND POWER CO-OP GETS ICBWR

Dairyland Power Cooperative finally appears on its way to getting a reactor—after wooing three. The LaCrosse, Wis., co-op reached agreement in principle with AEC on contract terms covering construction and operation of the 50-Mwe Improved Cycle Boiling Water Reactor. This is the unit that was to have been built by Los Angeles Dept. of Water & Power with Pasadena Municipal Light & Power Dept., but it was dropped as result of siting difficulties (NU, March '61, 24). ICBWR has now been redesignated LCBWR, for LaCrosse Boiling Water Reactor. Allis-Chalmers, AEC's choice to build ICBWR (after a re-study and re-award had taken the job away from General Electric), remains as builder of LCBWR—still a forced-circulation, internal-steam-separation prototype. Allis would design and build it and train Dairyland crews to operate it, under a $10,775,495 contract; AEC will own the reactor; Dairyland will build the turbine-generator plant and pay AEC 24.8 cents/million Btu for reactor steam. Total capital cost to Dairyland is put at $7,848,500. The 10-acre site near Genoa, Wis. (16 mi from LaCrosse), has already been approved by the Advisory Committee on Reactor Safeguards; LCBWR is the third reactor Dairyland has tried to put on the site, SSPWR (Small-Size Pressurized Water Reactor) and the Improved-Cycle Organic Reactor having been objects of earlier proposals before Dairyland filed an unsolicited proposal—on ICBWR when LADWP withdrew. The Joint Committee on Atomic Energy promptly called a hearing on AEC's proposed contract terms with Dairyland and with Allis.

CONGRESS VOTES NUCLEAR FRIGATE, TEN SUBS

Authorization for Navy construction of a second, $112-million nuclear frigate (USS *Bainbridge* is the first) was approved last month by a joint conference committee of the House and Senate; endorsement by full House and Senate was expected routinely. The bill also includes ten more Polaris submarines, raising the total to 29. Authorization of the frigate (a destroyer leader) was a compromise between the two approved by the House and none approved by the Senate. The House Armed Services Committee had substituted two nuclear frigates for three conventional frigates requested by the Administration under a "two-for-three" formula. The Committee noted that the cost of a nuclear ship has declined to the point where the Navy can buy two for the price of three conventional ships.

The action was merely the most striking of several indications that nuclear surface ships in large numbers are coming into serious consideration, even though their declining cost had not yet declined to equality with conventional ships. "Beginning next year, all Navy combat ships over 8,000 tons that we build, notwithstanding the higher cost, we should try to build with nuclear propulsion," Rep. Carl Vinson (D-Ga.), chairman of the powerful House Armed Services Committee, told NUCLEONICS. "We think nuclear-propelled ships are better; we should build nuclear ships, not withstanding the cost." Admiral Ramage of the Chief of Naval Operations' staff, told the Committee April 24, "In our long-range objectives, we have included two DLGNs [nuclear guided-missile frigates] per year henceforth. . . . on the basis that from 1963 on they would all be nuclear powered." And Admiral Rickover told the same committee meeting, "You can resolve the problem [of the Navy's needs for a minimum number of ships to meet commitments] in one of two ways: you can appropriate more money, or you can provide that we have sailing ships. . . . If the primary consideration is numbers, your committee might consider going back to sailing ships."

Meanwhile, NUCLEONICS learned that both the cruiser *Long Beach's* reactors are critical; the country's first nuclear surface ship is slated to make her initial sea trials early in July. Full-power-range testing and shield testing have been proceeding satisfactorily.

WORLD NEWS

Westinghouse Gets Study in Sweden

Following up its success in West Berlin (NU, June '56, 25), Westinghouse landed a contract to evaluate a 250-Mwe nuclear power plant for Sweden's national grid. Westinghouse again is key member of a three-company partnership: Bechtel Corp. is associated as architect-engineer, and the A. Johnson Co. of Stockholm (iron and steel, heavy metal fabrication, oil refining, shipping, etc.) as Westinghouse's representative in Sweden. The study they will carry out jointly for AB Atomenergi, Sweden's national atomic energy company, is a combination economic feasibility study and conceptual design. Reactor type is described as "homogenized pressurized heavy water," which covers various permutations of a D_2O-moderated and -cooled reactor. Whether moderation and cooling would be carried out by separate, independent D_2O loops or in a single circuit is one of the points to be studied. Both natural-uranium and slightly-enriched systems will be investigated. The work will occupy about eight months, and results are to be reported by year's end. Should Sweden decide to continue on to construction, it is expected the plant would be financed primarily or wholly by the government and would be a part of the State Power Board grid.

AMF Studies Superheat for Italy

AMF Atomics has a major nuclear-power job again: a design contract, jointly with its British associate, Mitchell Engineering, for a boiling-water superheat reactor for the Larderello Co. of Italy. Larderello, 45 mi south of Florence, is a region of 212–250° F geothermic steam jets, harnessed to a 150-Mwe generating plant that helps supply Italy's highly-electrified railways. (The Larderello Co., originally private, is now owned 75% by the State Railways.) It is to upgrade this low-temperature steam and increase its slackening quantity that Larderello has turned to Mitchell (as prime) and AMF to design a nuclear superheat reactor suitable for integration with the existing facilities. The reactor would be 110 Mwth, 25–30 Mwe, with a $5.6-million ceiling. The study is to be completed by August; if it indicates feasibility, Larderello will ask bids, in Italy and abroad, on building the plant.

SENA in Clear Again on Financing

The problem regarding Belgian government financing of the Belgian share of SENA reactor costs, which has been holding up work at the site near Givet, has now been overcome, and is spoken of by the sponsoring bodies as "no longer any difficulty." The Belgians are making preliminary arrangements regarding a second SENA plant they will build in partnership with Electricité de France—this one on the Belgian side of the border.

RWE Studying Big Reactor Again

Rheinisch-Westfälisches Elektrizitätsgesellschaft of Essen, West Germany's biggest electric utility, is examining proposals on a 250–300-Mwe power reactor and expects to put evaluation results up for discussion by midyear. RWE, which built the 15-Mwe demonstration boiling-water reactor at Kahl, has entertained plans for a large-scale unit since 1957, but in the last two or three years its interest has seemed rather platonic if not dormant. The company still stresses that it sees no possibility yet for producing nuclear power at competitive costs; nevertheless it appears as though chances of RWE's actually undertaking construction of a big reactor may be improving.

Eurochemic Progressing; Costs Up

Work on the 13-nation Eurochemic reprocessing plant at Mol, Belgium, continues despite a financial hitch that developed when cost estimates based on the recently-completed preliminary design turned out to be $9-million higher than the $21.5-million original estimate for plant construction and operation during the first five years. The question is not whether Eurochemic can raise the additional money, but merely how to split up the additional cost among the participating nations. Two main reasons for the higher cost: 1. a more sophisticated dissolver was added, to handle enrichments "much higher" than the 1.6% which the original dissolver can take; 2. more detailed and accurate calculations that became possible after St. Gobain had completed preliminary design of the plant. Also contributing: higher offsite development costs such as plant access road, housing, and a contribution to the Mol school for staff children.

Calder Power Output Up

Electrical output at Calder Hall and Chapelcross is up 28%, thanks to increases in the thermal output of each of the eight reactors from design rating of 180 Mwth to 225 Mwth, the Atomic Energy Authority says. The turbines, each originally rated at 21 Mwe (two per reactor), are being rebladed and will generate 27 Mwe; three are already back in service at the higher output. Main factor behind the increases, NUCLEONICS learns, is a 10-degree increase in mean fuel temperature, from 408 to 418°C (766 to 785°F). This is utilized by increasing coolant-gas flowrate while apparently holding constant the gas outlet temperature. In addition, smaller gains were made possible by greater flux flattening, increasing mean flux level.

Halden Completes 1st Core Operation

Halden, world's only heavy-water boiling reactor, completed operations on its first core and has been shut down for modifications to accommodate the second. All planned experiments with the first core were completed successfully, at operating powers up to 6 Mwth and temperatures to 310° F. The second core will operate at full design power level of 20 Mwth, at 450° F after the modifications are completed in December. Until now steam had been dumped; in 1962 the reactor will be connected to the steam distribution system of the adjoining Saugsbrugsforeningen paper factory. The reactor, built by Norway's Institute for Atomic Research, is operated by the European Nuclear Energy Agency.

Iraq Buys Russian Reactor

Russia has sold Iraq a research reactor, one of the 2-Mwth small pool—or well—types the Soviet Union has supplied to most East European countries. A contract was signed for supply, construction and operation, after the reactor design had been approved by the Iraqi Economic Planning Board. Russia will also build, equip and operate a laboratory for production of radioisotopes. Both will be at the Tuwaitha Atomic Center, at Baghdad.

SELNI Primary Plant 60% Fabricated

Fabrication of primary components for SELNI's 165–Mwe reactor is 60% completed. The pressure vessel, biggest yet for a reactor, is completed and being tested, as are main pumps and valves for the four coolant loops. All are to be shipped by year's end to the site at Trino between Milan and Turin. Foundation work there is proceeding; operation is to start in 1964.

NEWS IN BRIEF

Forum Group Suggests Site-Criteria Revisions

The Committee on Reactor Safety of the Atomic Industrial Forum last month submitted to AEC an extensive, proposed revision of AEC's suggested site-criteria for power and test reactors (NU, May '61, 17). In a covering letter signed by W. Kenneth Davis of Bechtel Corp., it was pointed out that a working group under D. Roy Shoults of General Electric Co. had carried out the redraft and that it reflected their individual views, rather than those of their companies. Davis said the redraft would drop test reactors from the criteria and also:

1. Assure that the example calculation in the AEC version would not be considered an integral part of the criteria. The Forum group added three examples to the AEC example to "emphasize a range of possible design-site relationships and that a proposed site can be evaluated only in connection with the engineering features of the proposed reactor."

2. Delete the population-center-distance concept proposed by AEC, on the premise that any additional distance factor determined by multiplying AEC's proposed low-population radius "by the arbitrary value of 1½ is without technological basis. We suggest that this concept should be replaced by a man-rem radiation-exposure limit to be expressed as a function of population distribution and density. The AEC or Federal Radiation Council should undertake to develop such a concept."

3. "Focus more attention on the importance of the interrelationship between design, site characteristics, distance and population density."

The Davis letter also made this point: "We cannot over-emphasize the impact which we believe the establishment of site criteria will have on reactor development in the U. S. and on friendly nations abroad. . . ."

AEC Makes Additional Regulatory Staff Changes

In a followup on its March 10th action which separated regulatory functions from operational and developmental functions (NU, May '61, 27) the AEC has made additional staffing and organizational changes in its regulatory program. The Office of Health and Safety has been divided into two sections: the Office of Radiation Standards, headed by Forrest Western, which will perform such regulatory functions as development of basic radiation standards, and development of AEC-State relations in the field of licensing and regulation; and the Office of Operational Safety, headed by Nathan H. Woodruff who will report directly to General Manager A. R. Luedecke on research, industrial and radiological safety.

Other changes: transfer of regulatory field inspection personnel in the AEC operations offices to the direct authority of David Low, director of the Division of Compliance; separation of the Division of Licensing and Regulation's responsibilities for licensing, enforcement proceedings and development of guides and regulations to permit more emphasis on guides and regulations. Because of this increased emphasis, Harold L. Price, acting director of regulation, has appointed a standing Rules Clearance Committee which will report directly to him. In addition, Joseph DiNunno will head the reactor standards staff and report directly to Robert Lowenstein, director of the Licensing and Regulation div.

Commerce Dept. Reports on First Instrument Survey

The Commerce Dept.'s Business and Defense Services Administration issued in late May the first statistics ever compiled on shipments of the radiation-instrument industry. Covering the year 1959, the report said shipments were at least $46-million that year; and BDSA officials estimated that the actual total was more than $50-million, counting products of nuclear-instrument firms not included in the $46-million figure because they were covered in other government surveys. BDSA also emphasized that the survey would not be repeated unless a trade association representing the radiation-instrument industry, or enough industry firms individually, petitioned BDSA to carry out the survey periodically.

The '59 survey questionnaire went to more than 600 firms; 135 of these were identified, on the basis of their returns, as nuclear-instrument makers. Since '59, BDSA estimates, another 25 firms have gotten into the field to make the total about 160. Values of major categories of instruments shipped in '69 were: gaging and process-control instrumentation, $6,567,000; power supplies, $6,260,000; portable survey instruments, $6,434,000; detecting heads sold separately $4,584,000; monitoring instruments, $4,522,000; pulse-height analyzers, $3,524,000; amplifiers, $3,220,000; scalers, $2,878,000; dosimeters, $1,903,000; count rate meters, $1,385,000; and radiation sources, $1,683,000. A detailed report on the survey will be published eventually as part of a major report on all types of instruments.

JCAE and Space Race Spur Reclassification of SNAP

The AEC, pressurized by demands from the Joint Committee on Atomic Energy that tighter restrictions be imposed on the flow of SNAP data (Systems for Nuclear Auxiliary Power), and the urgency of the race with Russia for conquest of space, has reversed its earlier trend toward declassification of SNAP information. In confirming the Commission's revised attitude, an AEC official said he expected "all space and military SNAP projects" to become "essentially classified." However, there will be no attempt to reclassify data already made public. "If we continue to operate completely in the open," he said, " . . . this would be to the advantage of the Russians. We publish everything and they publish nothing." The tightening up could affect such SNAP projects developed purely for nonmilitary and nonspace applications as weather data-gathering, power for oceanographic devices, navigational devices, etc., when these applications involve the use of classified data. As a result of the Commission's decision, revised SNAP classification guides will probably be distributed to SNAP contractors this month.

Ward Appointed Inter-Industry Group Chairman

With the recent appointment of former Vitro Corp. Chairman J. Carlton Ward as chairman of the Inter-Industry Advisory Committee on Government Competition, the Committee, which was proposed last fall (NU, Oct. '60, 30; NU, May '61, 24), is now ready to actively undertake a program designed to coordinate the activities of its four member groups—the U. S. Chamber of Commerce, Edison Electric Institute, Manufacturing Chemists' Assn. and the National Assn. of Manufacturers. Ward, whose principal task will be to promote industry participation in the nuclear field, met in late April and early May for the first time with JCAE Chairman Chet Holifield (D-Cal.), AEC Commissioners Glenn T. Seaborg, chairman, and Robert Wilson, and Ernest Tremmel, head of the new AEC Office of Industrial Participation. After the meetings, Ward said the Inter-Industry group hopes to work closely with the Commission to carry out the stated purposes of the 1954 Atomic Energy Act on a policy making level. Tremmel, who will work closely with Ward on program development, plans frequent meetings with the industry group leader.

RADIATION NEWS

Baird, Nuclear Industries Settle Out of Court

Baird-Atomic and Nuclear Industries, Inc., last month settled out of court Baird's suit against NI (NU, May '61, 28) and an earlier suit filed against Baird by an NI vice-president, Louis Mead. Authoritative industry sources said the settlement included: payment of an undisclosed amount of cash by Baird to Mead (the latter had sued for release of Baird stock held in escrow); and NI committed itself against approaching Baird employees or firms associated with Baird for certain periods of time.

Anton Leaves His Firm After Management Difference

Nicholas Anton has resigned from the company he founded 12½ years ago—Anton Electronic Laboratories, Brooklyn; he has been succeeded by Walter K. Volkers, former vice-president for research and development at Massa div. of Cohu Electronics. Anton's resignation, he said, was prompted by a difference of opinion with Lionel Corp.—controller of Anton Labs since last September—over integration of the Labs into the Lionel complex. Anton indicated Lionel would assume sales and other service responsibilities, with the Labs concentrating on research-development and production. In the process, the name has been changed to Lionel Electronic Laboratories. Anton said he had no plans other than to take a long European vacation.

Anton

RDI Buys 80% Interest in New Physics Firm

Radiation Dynamics, Inc., Westbury, L. I., radiation-machine manufacturer, last month announced its first acquisition: purchase of an 80% interest in Advanced Research Corp., Lafayette, Ind., a new theoretical-physics firm created by Purdue Univ. and other physicists to do consulting and contract research. RDI also said it was negotiating with U. S. financial interests and with Adany Laboratories, near Paris, to establish a U. S. company in the electronics field; radiation may or may not be involved in this company's products. Adany and RDI are already partners in a program to set up an irradiation center at Adany's headquarters before the end of this year (NU, Apr. '61, 27). RDI's purchase of a controlling interest in Advanced Research Corp., is expected: 1. to increase RDI representation among campus users of particle accelerators (because Advanced Research people will be consulting on university research programs across the country); 2. bring a cross-fertilization on research contracts sought by each firm; and 3. possibly produce ideas for new RDI products.

Seaborg to Seek 50–100% Increase in Isotope Funds

AEC Chairman Glenn T. Seaborg disclosed last month that he will seek an increase of 50–100%, in fiscal year 1963 (beginning July 1, 1963), in the budget for AEC's Isotope Development Program. In an interview (*see page 26*), Seaborg called AEC's request of $5.5-million for fiscal '62 for the Isotope Development Program "pitifully small." He has indicated he would also like to see more AEC funds made available for support of low-energy physics research (under 100-Mev), possibly including funds for purchase of new and replacement radiation machines by universities and colleges.

AEC to Expand Isotope Separation Facilities . . .

The hopes of private firms interested in building radionuclide separations or recovery facilities—notable among these Martin Co. and Air Reduction Co. (NU, June '61, 27)—were set back last month when AEC announced that it had decided to build new capacity at Hanford Works. Martin and Air Reduction, looking toward the use of megacurie quantities of strontium-90 and other radionuclides in isotopic generators, had informally proposed the construction of their own plant at Hanford. But, it is understood, this was blocked in large part by AEC's inability to give guarantee of feed-material supply—primarily because of the uncertain future of Hanford's reactors. An East-West agreement banning nuclear weapons, for example, could shut down the production reactors. AEC officially explained:

"The Commission considered formally inviting private industry to undertake the recovery operation. However, indications are that, at present, it would be more feasible for the AEC to recover the fission products and offer them for sale to industry for final processing, fabricating and marketing. AEC's Office of Industrial Participation will informally explore further the interest of industry in participating, with private funds, in the recovery of isolated fission-product compounds."

. . . While Extending a Contract on Mixed Wastes

Shortly before its announcement on expanding Hanford's radioisotope-separation capacity, AEC had extended for a year its support of a development program at General Instrument Corp., Newark, N. J., looking toward the large-scale use of unseparated fission wastes (NU, Oct. '60, 30). Sponsor of the work is AEC's Reactor Development div. under the SNAP program (Systems for Nuclear Auxiliary Power). Under the contract extension ($150–200,000), GIC is to deliver by next spring a 3–5-watt prototype generator designed to use the wastes to be produced by the Idaho Calcination Process Plant, which is to go on the line early next year. GIC's initial unit will be electrically heated but a fueled experiment would follow under the next phase of the program.

Goal of the program is to use mixed wastes "as is, or as nearly as possible as is," it was pointed out. GIC is trying to achieve a generator size no larger than a two-ft diameter sphere, operating at 100–200° C; the major technical challenge is the densifying of Idaho—and, eventually, civilian-reactor—wastes by developing binding, crushing and pressing techniques.

RIDL Claims 40% of Multi-Channel Analyzer Sales

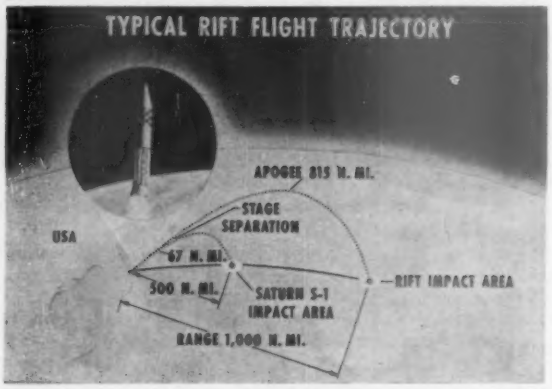
Radiation Instrument Development Laboratory, Inc., which is "going public" via the sale of 100,000 shares of common stock at a maximum of $13/share, or $1.3-million (NU Wk, 8 June '61, 2), believes it accounts for 40% of all multi-channel analyzers sold. During the year and nine months ended March 31, 1961, sales of these analyzers, ranging in price from approximately $10,500 to $18,500, accounted for about 60% of the company's total dollar volume. In the first disclosure of its earnings history, RIDL reported earnings of 41¢/share for the nine months ended March 31 (based on the 333,333 shares to be outstanding after the public stock sale), compared to 14¢/share for the year ended June 30, 1960. Earlier earnings: 10¢/share, 1959; 18¢/share, 1958. Sales have increased steadily from $909,156 in 1958 to $1,516,874 for the nine months ended March 31, 1961, a figure that already tops the $1,509,741 totaled for the year ended June 30, 1960. Order backlog as of Apr. 30 was $605,194, about 38% of it government business.

SPACE NUCLEONICS

Marshall Study Contracts Highlight Rocket News

In a series of developments on the nuclear-rocket program last month (*also see page 25*): 1. Marshall Flight Center awarded two study contracts on the integration of nuclear upper-stage vehicles with Saturn chemical boosters; 2. AEC and NASA announced some details of the Kiwi-B reactor test series to begin this fall (NU, May '61, 22); and 3. Harold B. Finger, director of the AEC/NASA Space Nuclear Propulsion Office, disclosed details of the proposed flight-test of the first nuclear rocket as recommended by industry contractors under the RIFT program (Reactor-in-Flight-Test).

Marshall Flight Center. In its first formal support for studies entirely concerned with nuclear vehicles, NASA's Marshall Flight Center, Hunstville, Ala., awarded contracts to General Dynamics' Astronautics div. ($112,636) and Lockheed Aircraft's Missiles and Space div. ($128,804) for studies on integrating nuclear second and third stages into the Saturn system. The concept is referred to informally as Saturn D (NU, May '61, 22); Marshall is to manage vehicle integration and flight-testing of Saturn-nuclear systems when these systems are ready. The two contracts are for six-month periods and will cover: estimates of feasible nuclear-engine thrusts for different configurations; scheduling and funding of nuclear stages; and consideration of nuclear integration with advanced Saturn boosters. Marshall is also supporting study contracts where nuclear vehicles are being considered as eventual boosters.



Flight-Test Data. Finger, in a paper as the First National Conference on Peaceful Uses of Space, Tulsa, revealed a few more details of the likely first flight-test of a nuclear upper stage to be launched from Cape Canaveral by a Saturn S-I booster. The nuclear stage, probably of 1–2,000 Mw, would be lobbed downrange 1,000 mi (see illustration), reaching an altitude of 815 mi. The nuclear engine would be started "at altitude [after S-I separation], as would be the case in an operational mission," Finger said. Formal target dates for flight test are 1966–67, though many in the program feel that a 1965 flight is possible.

Kiwi-B Test Series. AEC/NASA formally confirmed that first reactor in the Kiwi-B series—this fall—will be cooled with gaseous, rather than liquid, hydrogen. Thus, the first liquid-H test will not be run until early in 1962 and this is to be followed by as many as 3–5 more during the year. The B series is to lead to a "breadboard" engine—reactor, liquid-H turbopump feed system, liquid-H-cooled jet nozzle and system controls. Los Alamos Scientific Laboratory, developer of the reactor, feels it may be able to turn over the essential details on an engine reactor—to the engine contractor (*see page 25*)—midway in the '62 series, if no major problem arises. Test Cell D, to be the first down-firing engine test stand, is scheduled to be ready for use early in 1963—west of Test Cells A and C at Jackass Flats, Nev., which are to be used for the up-firing Kiwi-B series. Jackass Flats has been tentatively designated the National Nuclear Rocket Development Center.

TEECO Developing 5–8 Watt Thermionic Device

Thermo Electron Engineering Co., Waltham, Mass., is developing a 5–8-watt thermionic converter for possible use with curium-242 in a space auxiliary-power device; TEECO is a subcontractor to Martin Co., prime AEC contractor on the use of radioisotopes as heat sources for SNAP systems (Systems for Nuclear Auxiliary Power). A prototype device of the curium converter has been operated through a 1,000-hr test run, reaching a power output of about two watts; the thermionic device is a cylindrical vacuum unit with thermionic converters at either end. TEECO is also developing a vapor-diode thermionic converter for use with radionuclides. Its current contract with Martin is about $225,000.

ARS Schedules Space Report to Nation

A massive technical meeting/exhibition titled "Space Flight Report to the Nation" has been scheduled by the American Rocket Society for Oct. 9–15 in the New York Coliseum. Wernher von Braun, director of Marshall Flight Center is chairman of the "Report," which has been scheduled primarily to give the general public a better understanding of the space program to gain public support for the expenditure of the many billions of dollars that will have to be budgeted over the coming years. Aside from the public-understanding nature of the "Report" (including nationwide televising of three special panels on space), there will be as many as five technical sessions running simultaneously on any given morning, afternoon or evening. Specific nuclear sessions will include: nuclear-propulsion test facilities, power sources for electric propulsion, nuclear-rocket mission studies, nuclear instrumentation, ramjets, magnetohydrodynamics and environment of space. Convair's Krafft Ehricke will moderate a televised panel session on space vehicles.

AGN Sets Up Electrical Propulsion Group . . .

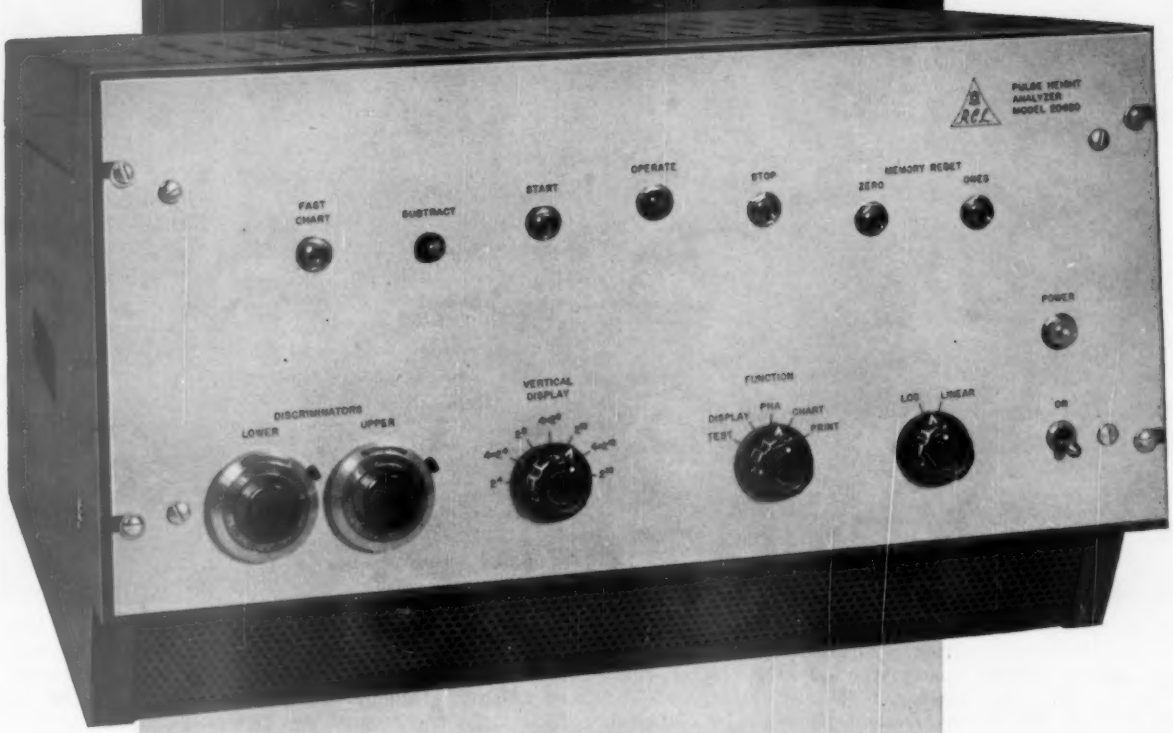
Aerojet General Corp. has formed an electrical propulsion group within its Nucleonics div., San Ramon, Calif., and the group has been awarded its first contract—a $200,000 contract from the Air Force for study of plasma physics. The group is headed by John Luce, formerly of Oak Ridge National Laboratory's fusion program, who, AGN hopes, will put together one of the most capable electrical-propulsion teams in the U. S.

In another nuclear-space development, AGN had earlier moved into the second year of its subcontract with Garrett AiResearch div., on studies of a space reactor in the range 0.3–1-Mw (Project Spur: Space Power Unit Reactor). Sponsor of the study is the Air Force, with Westinghouse also participating on design of special moving parts for the generator.

. . . and Boeing May Establish Nuclear Rocket Group

A small "four or five-member study group" at the Boeing Co.'s Seattle, Wash., facilities was about ready early last month to make a proposal to management on the possibility of Boeing's entry into nuclear rocketry. If management gives its okay, the group would be expanded and, presumably would bid on the nuclear-vehicle development invitation expected from NASA later this year.

INTRODUCING A NEW CONCEPT IN PULSE HEIGHT ANALYZERS



New low cost 128 and 256 channel pulse height analyzers

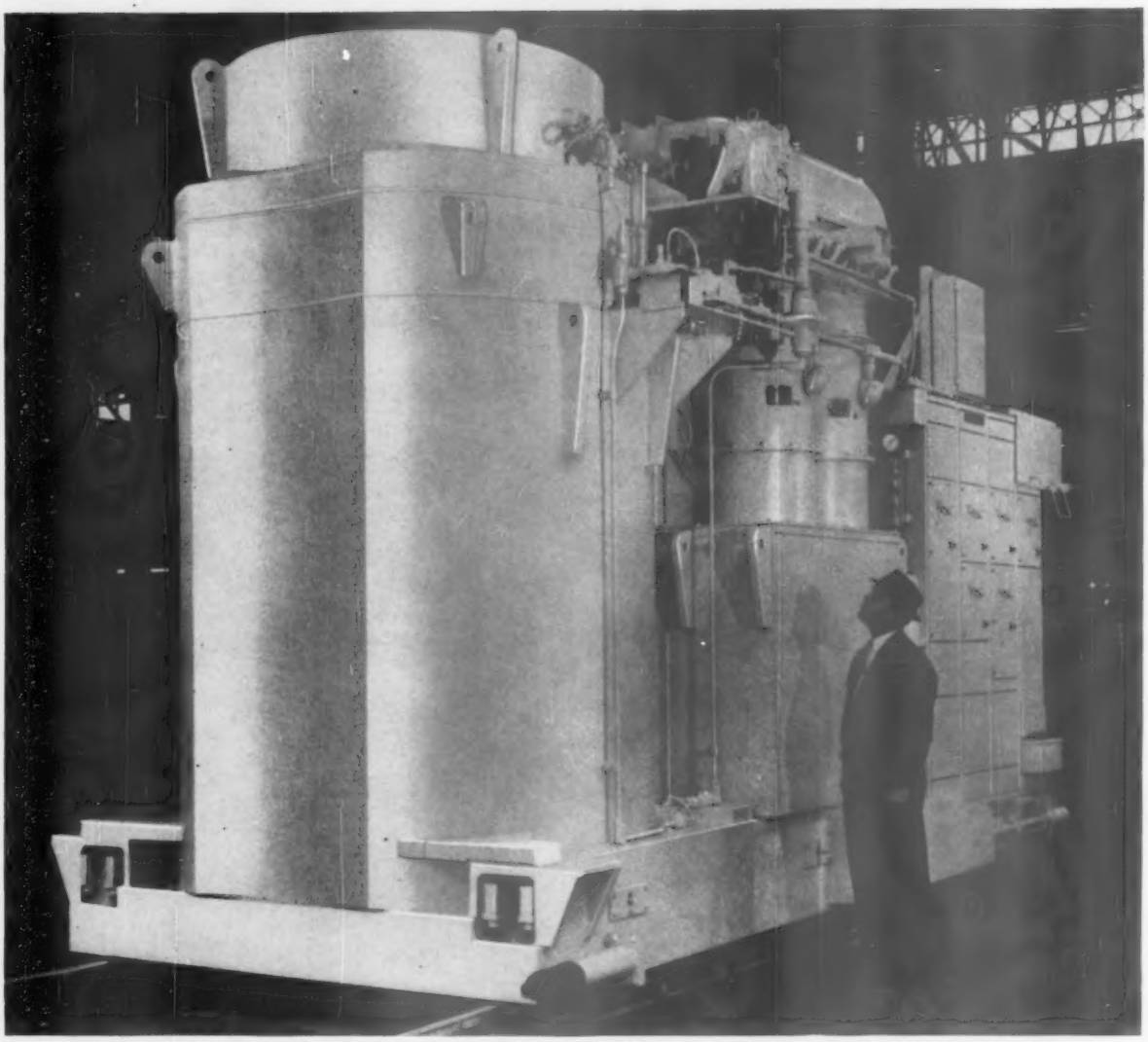
Specially designed for budget conscious laboratories or laboratories requiring additional analyzers for less sophisticated work, these completely new analyzers feature . . . Advanced high speed transistor circuitry including crystal control oscillator and 5 MC scaler . . . All transistor circuitry is on plug-in cards for easy access . . . Plug-in Cards have bifurcated and double-sided contact pins to assure extreme reliability . . . New Dead Time Specification—(12.5 plus 0.2N) μs . . . Removable Power Supply . . . Simplified Operating Design.

For additional information or a demonstration of these Analyzers, contact RCL or your nearest RCL Representative.

RCL

RADIATION COUNTER LABORATORIES, INC.

5121 West Grove, Skokie, Illinois, U.S.A., YOrktown 6-8700



Fuel transfer cask car shown in plant of its builder, Baldwin-Lima-Hamilton, Philadelphia, prior to rail shipment to Enrico Fermi Atomic Power Reactor, near Monroe, Michigan. The car, 22′ long, 10′ wide, 13′ high, weighs about 200 tons. Gamma shielding by National Lead Company consists of about 170 tons of lead and about 7 tons of depleted uranium. Power Reactor Development Company built the nuclear portion of the plant in which this unique vehicle will operate, and Detroit Edison Co. constructed the turbine generator section.

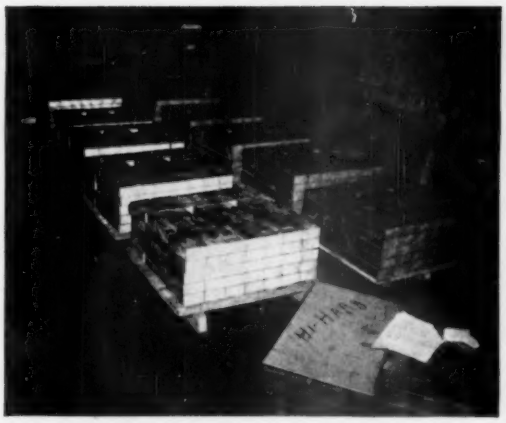
You get more than metal in gamma

You get two exclusive built-in extras: the *result* of the lead handling know-how of the world's largest fabricator of lead products... the *effect* of the mutuality of interest engendered by National Lead's own activities in the nuclear industry.

Working with lead for many years in many fields, National Lead has built up a vast fund of experience in handling the metal. This know-how is expressed in lead grade selection, alloying practices, fabrication methods, casting temperatures, cooling rates, bonding techniques and other areas vital to quality. Thus, National Lead knows how to make the most of lead's gamma attenuation properties.

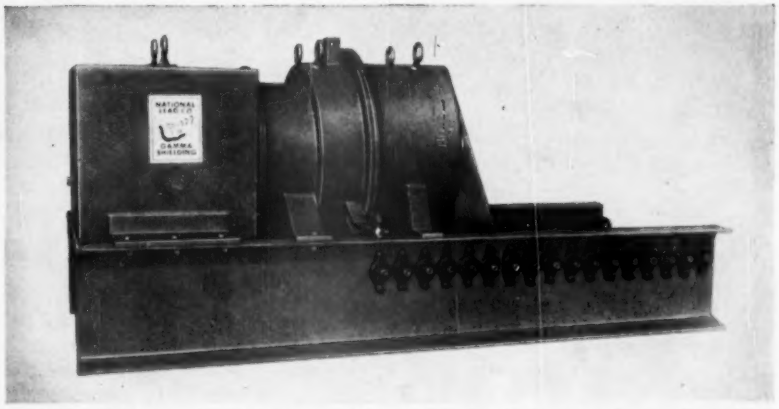
The other built-in extra is the "feel for the function" of the shieldment. The design, engineering and production of National Lead shielding benefits by the supervision of men thoroughly versed in nuclear arts and sciences. National Lead has its own Nuclear Metals Division, is a co-owner and operator of Industrial Reactor Laboratories at Plainsboro,

Fuel handling device built by Atomics International for the AEC, to be used at the Hallam, Nebraska, reactor operated by Consumers Public Power District. Among many other functions, this 54′ high, delicately controlled machine deposits and retrieves fuel rods when positioned over the reactor. Gamma shielding of the device consists of 118 tons of National Lead Company's lead shot.



"Hi-Hard" lead brick, about two tons to a pallet, being prepared for shipment on an order totaling 100 tons. Since introducing "Hi-Hard" some years ago, National Lead has supplied large tonnages of these bricks, in several sizes and shapes, for gamma shielding installations around the country. Having a Brinell hardness of around 20 (as against about 4 for regular lead), "Hi-Hard" brick withstands considerable handling abuse before consignment to the discard pile. With a small mark-up over the regular brick, the "Hi-Hard" variety is a real buy for any purchasing agent.

Transfer cask. This 8-ton cask and 12 storage shrouds were built by National Lead for the Indian Point Generating Station of Consolidated Edison Co. of N. Y., Inc.



CO-60 irradiator produced for Republic Electronics Industries Corp., Farmingdale, L.I., New York, by National Lead.

shielding supplied by National Lead

New Jersey, operates for the AEC the Fuel Materials Production Center at Fernald, Ohio, and the Research Laboratory at Winchester, Massachusetts. In many important ways, these interests are reflected to the customer's benefit in gamma shielding designed and produced by National Lead.

* * *

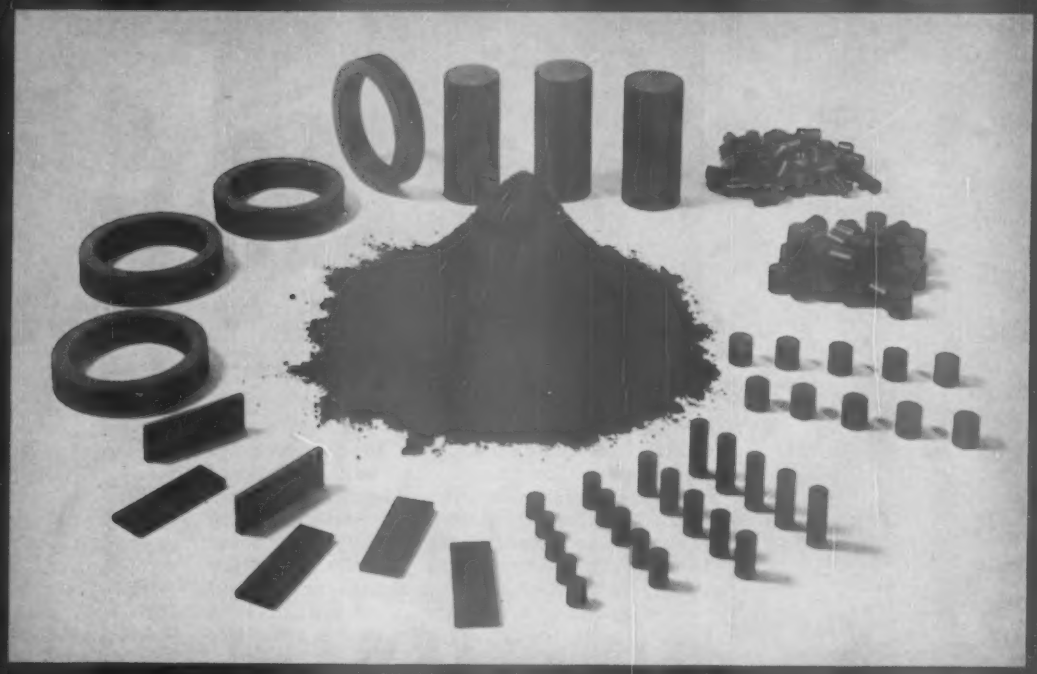
When you need shielding, whether of lead or depleted uranium, off the shelf or made to order, get in touch with our nearest Branch.

This trademark is the symbol of National Lead Gamma Shielding.

NATIONAL LEAD CO. Pb = GAMMA SHIELDING

National Lead Company

General Offices: 111 Broadway, New York 6, New York • Branches in all principal cities

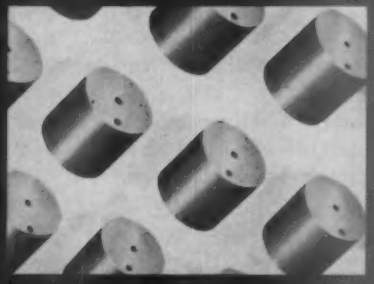


NUMEC to supply entire UO_2 powder requirement for Yankee Core II

Quality products = Repeat business

Westinghouse Electric Corporation has again come to NUMEC for fuel material for Yankee. After supplying 50% of Core I UO_2 powder, NUMEC has been selected to supply all UO_2 powder for Core II. This high quality material will be produced in NUMEC's new conversion plant under the best controlled and most efficient production techniques available today.

NUMEC'S PRODUCTS AND SERVICES INCLUDE: . . . ceramic fuel materials and fabricated forms . . . moderating and control materials . . . coated particles and parts . . . scrap recovery of unirradiated U and Pu materials . . . radio isotope sources, including Pu: Be sources . . . analytical, metallurgical, research services . . . special equipment for materials fabrication and research.



NUMEC®

nuclear materials and equipment corporation

apollo, pennsylvania, u.s.a.

cable NUMEC • telephone GRover 2-8411

The UO_2 pellets shown at the left illustrate some of the difficult fabrication problems NUMEC has solved. As sintered, density is 94%; diameter .356" ± .002"; height .356" ± .010". Each pellet contains two thermocouple holes .032" in diameter. The edge of the outer hole is .030" from the periphery of the pellet.

Send for illustrated brochure describing these, and other, NUMEC products and services

NOW FROM STANDARD COMPONENTS ... YOU CAN BUILD HOT CELL AND UNDERWATER PERISCOPES LIKE THESE

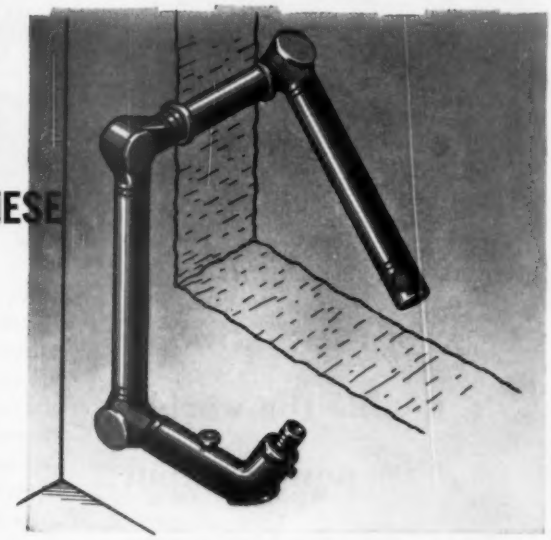
NEW KOLLMORGEN MODULAR PERISCOPES

At a fraction of the cost of a "special," you can put together a precision periscope that meets your exact requirements. Modular components can be assembled with a wrench in less than a day by following the simple instructions. The result . . . a high-quality, high-precision instrument made by Kollmorgen, the country's leading manufacturer of remote optical viewing equipment for the nuclear industry.

Kollmorgen Modular Periscopes are ruggedly constructed and incorporate optical systems of the highest quality. No matter how many right angle elbows are used, the image always appears erect. Easily disassembled, periscopes can be quickly relocated in different installations.

Non-browning glass and corrosion-resistant materials are used throughout. Periscopes are completely air-tight and water-tight. For additional specifications, prices and ordering information, write Dept. 2-7

POWER	FIELD	FOCUS RANGE	EXIT PUPIL
1½ x	32°	0 to infinity	4mm
3 x	16°	0 to infinity	2mm
6 x	8°	H₂0 3 ft. Air 27 in. to infinity	4mm
12 x	4°	H₂0 3 ft. Air 27 in. to infinity	2mm



KOLLMORGEN
CORPORATION
NORTHAMPTON, MASSACHUSETTS

NUCLEAR REMOTE VIEWING EQUIPMENT • SUBMARINE PERISCOPES • OPTICS • BORESCOPES • MOTION PICTURE AND TELEVISION LENSES • PRECISION OPTICAL INSPECTION AND ALIGNMENT DEVICES • ELECTRONIC CONTROLS AND COMPONENTS • NAVIGATIONAL AIDS

11,400 KW Organic Moderated Reactor plant for the City of Piqua, Ohio

The Peaceful Atom

Answering the challenge of the Sixties: to double the world's power output in ten years

To meet increased living standards everywhere, the world's power resources must be doubled in the 1960's. In this great expansion the Peaceful Atom will play an ever-increasing role. Atomics International, a leader in developing nuclear power for over 15 years, is already building two of the world's most advanced power stations under AEC programs: the Organic Reactor plant at Piqua, Ohio and the Sodium Reactor plant at Hallam, Nebraska. Another promising concept is the Advanced Epithermal Thorium Reactor project, now being developed by AI for the Southwest Atomic Energy Associates, a group of investor-owned utilities. AI's experience and facilities will play a growing part in meeting the power challenge of the Sixties.

ATOMICS INTERNATIONAL

Division of North American Aviation

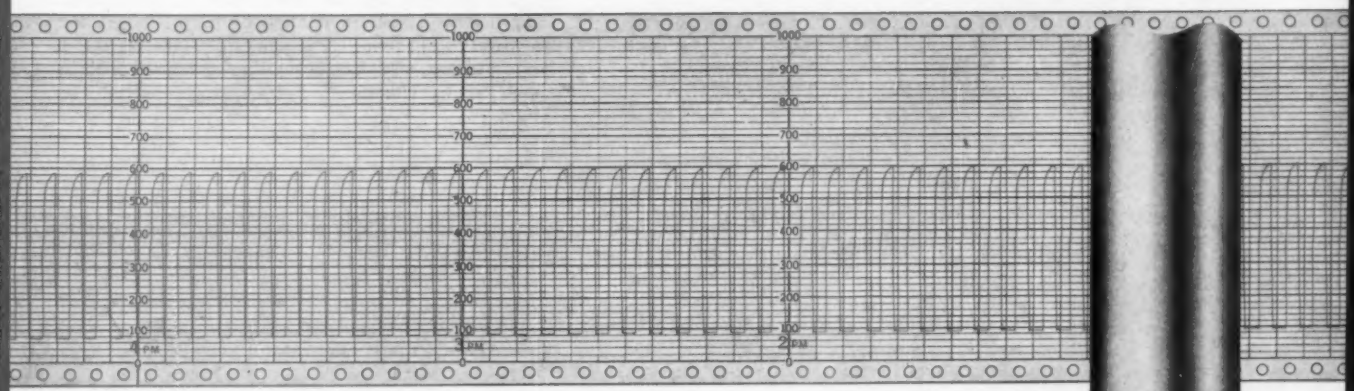
Pioneers in the creative use of the atom

World Headquarters: Canoga Park, California, U.S.A. Cable Address: ATOMICS. *Other offices:* Washington, D.C., U.S.A.; Geneva, Switzerland. *Affiliated with:* INTERATOM, Bensberg/Cologne, Federal Republic of Germany and DYNATOM, Paris, France

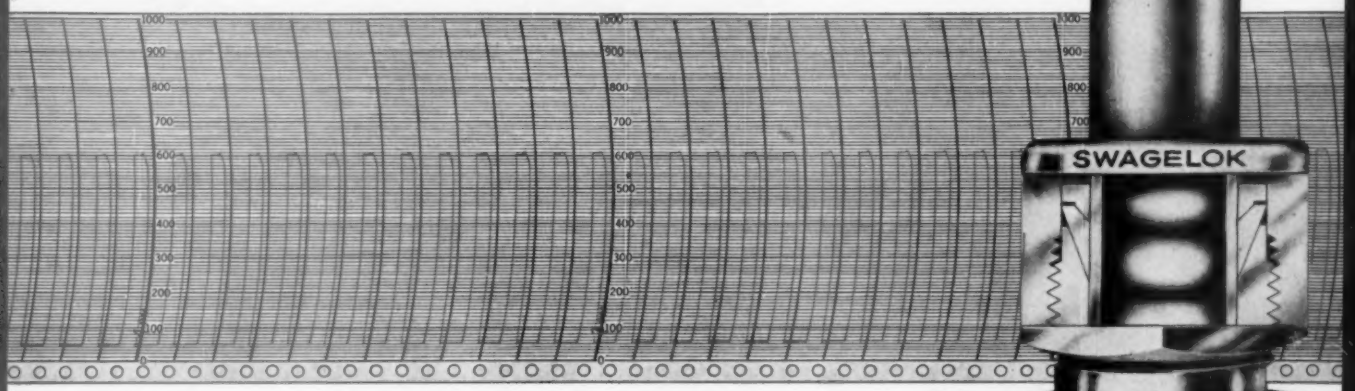
Severe Thermal Shock and Pressure Tests prove that

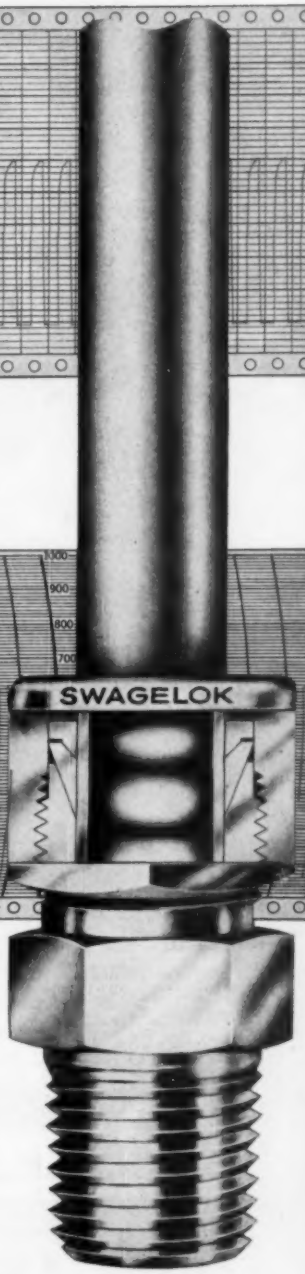
Swagelok® TUBE FITTINGS

SOLVE YOUR PROBLEMS



TEMPERATURE VS TIME RECORDING: The peak temperatures 580° to 600° F. occurred during the maximum pressure period. 750° F. steam was used but inability to keep insulation intact due to severity of the thermal shocks limited the maximum temperature. The minimum temperatures occurred during the cold water flush.





PRESSURE VS TIME RECORDING: The maximum pressures on the chart were produced by 600 psi superheated steam at a source temperature of 750° F. The minimum pressures were the result of opening the system dump valve and flushing with 50° F., 500 psi cold water.

The tests recorded on the above charts were conducted on one inch carbon steel hydraulic tubing (ASTM-A-179) using carbon steel SWAGELOK Fittings. Thirteen to sixteen SWAGELOK Tube Fitting connections were in the systems and 1200 severe thermal shocks were applied on each of two different tubing configurations without leaks or failure. The conditions used in this test were considered casualty or mal-operation conditions and are not recommended practice for any system design.

These tests prove that for steam system instrumentation and steam tracing service, SWAGELOK Tube Fittings solve your problem.

Swagelok® TUBE FITTINGS

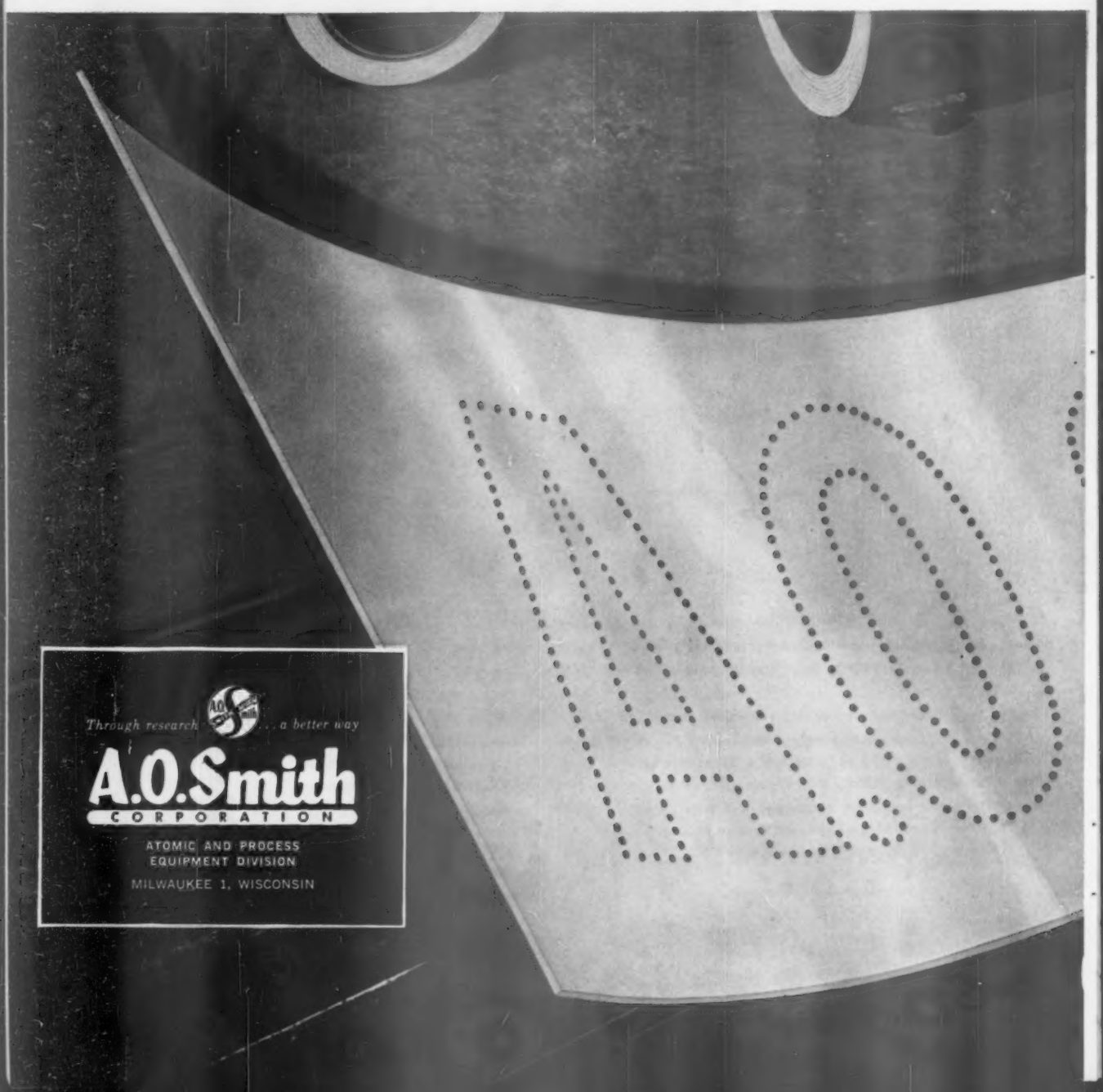
Crawford Fitting Company • 884 East 140th Street • Cleveland 10, Ohio • Crawford Fittings (Canada) Ltd., Niagara Falls, Ontario, Canada

big name in vessel reliability

a name backed by 35 years' experience
building stronger and safer process equipment

The demands of nucleonics for greater strength and safety in vessels, reactors and related equipment are not new problems for A. O. Smith. Our fabricating experience gained in the use of a wide range of metals to withstand unusual punishment is today proving a valuable legacy to nuclear power planners.

For example, A. O. Smith's Multi-Layer technique is now paying dividends in nuclear power. Westinghouse reports reactor vessels of Multi-Layer construction show promise of providing maximum economy, safety and manufacturing flexibility for use in future large plants. One such "steel wrapped in steel" reactor is now being installed for Saxton Nuclear Experimental Corporation, a subsidiary of the following General Public Utilities Corporation operating companies:



Through research . . . a better way

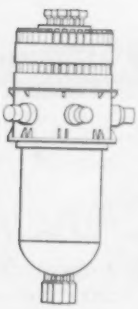
A.O.Smith
CORPORATION

ATOMIC AND PROCESS
EQUIPMENT DIVISION
MILWAUKEE 1, WISCONSIN

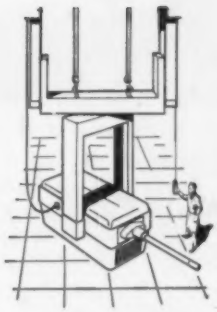
Jersey Central Power & Light Company, New Jersey Power & Light Company, Metropolitan Edison Company and Pennsylvania Electric Company.

This ability to meet the challenge of tomorrow is the reason more and more A. O. Smith atomic reactors, heat exchangers, core barrels and related equipment are included in today's power reactor plants and other nuclear developments.

WANT TO KNOW MORE ABOUT US? Then write for our new brochure titled, "From arc to atom." It tells all about the Atomic and Process Equipment Division of A. O. Smith — the full story on our facilities and abilities, including facts on A. O. Smith Multi-Layer.



INDUSTRY FIRST AT SAXTON — This Multi-Layer vessel to be used in a commercial power plant application. A. O. Smith built the vessel and pre-assembled the core support structure in the vessel. The main cylindrical shell course is composed of a ½-inch-thick stainless-steel-clad inner barrel and 18 layer wraps. Each relatively thin steel plate utilized in Multi-Layer vessels exhibits better metallurgical properties than solid wall.



QUALITY CONTROL — A. O. Smith's high standards for product excellence are a direct result of its "all-seeing" test program. This summer, an 8-million-volt linear accelerator will be installed at the Milwaukee plant. It will permit faster, more thorough radiographic inspection of welds in heavy pressure vessels.

COMPACT NEW MULTI-PURPOSE

RIDL MODEL 33-8

SINGLE-CHANNEL PULSE HEIGHT ANALYZER

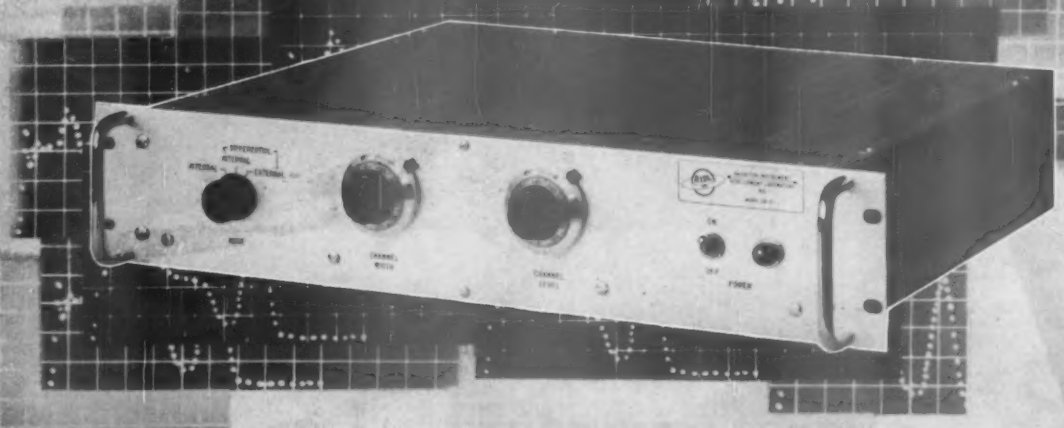
- **Complete unit in a 3-1/2" x 19" chassis**
- **Exceptional accuracy and stability**
- **Fast resolving time**
- **Lock-type RB-dials for drift-free operation**
- **Variable window width**
- **Integral or differential operation at the flip of a switch**

CONTINUOUS IMPROVEMENT through the adoption of printed circuitry and simplified design has made possible this newest analyzer in the RIDL line . . . the compact, versatile 33-8 Single-Channel Pulse Height Analyzer.

TESTED AND PROVEN version of the Oak Ridge Q-1192, the model 33-8 does the work of larger instruments quickly and accurately. It is designed to be used manually or with an electronic sweep such as RIDL model 39-2.

INTEGRAL OR DIFFERENTIAL OPERATION at the flip of a switch! Lock-type RB-dials make sure you stay on channel. Fast resolving time of ½ microseconds reduces dead time to a minimum. Output is negative. Positive output optional from all P.C. boards.

VARIABLE WINDOW, ZERO TO 100%! A major feature of the 33-8. When used with the RIDL model 30-16 Amplifier, the 33-8 Single-Channel Pulse Height Analyzer may be opened to 100% window. The discriminator control on the Amplifier is then used as an upper level. A 20% window on the 33-8 is optional at no extra cost. Window width stability is better than 1%.



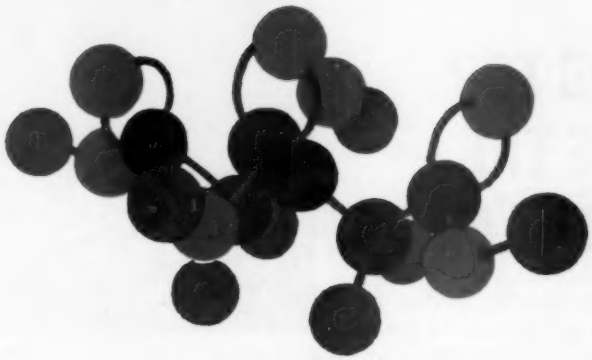
RIDL

FOR FULL DETAILS: write to Dept. S.

Radiation Instrument Development Laboratory, Inc.

61 EAST NORTH AVENUE • NORTHLAKE, ILLINOIS

PHONE: MUrray 1-2323 • Cable Address: RADILAB



UNIQUE COMBINATION OF ADVANTAGES OFFERED BY CITRIC ACID IN CLEANING NUCLEAR EQUIPMENT

PFIZER CITRIC ACID has already established itself as a completely acceptable, highly efficient agent for preoperational cleaning of atomic reactors and for radioactive decontamination of nuclear equipment. Most commercial nuclear power facilities presently in use have been successfully cleaned, at least in part, with citric acid.

Such widespread usage and approval is more understandable in view of the fact that citric acid alone offers all of these advantages:

PFIZER CITRIC ACID is a highly efficient cleaning agent which removes imbedded metal and oxide film from steel and stainless steel.

PFIZER CITRIC ACID's sequestering ability prevents reprecipitation of dissolved scale.

PFIZER CITRIC ACID is non-toxic and readily water-soluble—it is, therefore, both safe and easy to handle.

PFIZER CITRIC ACID provides the means to storage and handling economies—it is sold as a dry, 100% acid.

PFIZER CITRIC ACID can be effectively inhibited without losing either its cleaning or sequestering ability.

PFIZER CITRIC ACID completely eliminates the problem of chloride stress corrosion in cleaning nuclear equipment.

No wonder, then, that manufacturers and operators of atomic power equipment have approved the use of citric acid for cleaning boilers and heat exchangers, for flushing the pressure vessels of nuclear steam supply systems, and for numerous other jobs.

And responsible personnel are learning daily to think of Pfizer when the product is citric acid. Take advantage of the long-standing experience of Pfizer in producing citric acid.

Write today on letterhead stationery for your free copy of Pfizer's technical literature on nuclear equipment cleaning: Chas. Pfizer & Co., Inc., Chemical Division, Brooklyn 6, New York.

Science for the world's well-being®

Pfizer

CHEMICAL DIVISION

FOR YOU TO ADVANCE THE STATE OF THE ART

The Westinghouse Testing Reactor facility in Waltz Mill, Penna. provides the reactor designer with a completely instrumented facility from which he can derive empirical data to correlate with his design equations. This kind of "in-field" approach enables Westinghouse to stay in the forefront of reactor technology.

FOR A LARGE SCALE EXPERIMENTAL REACTOR

Westinghouse scientists and engineers will soon enjoy the unique technical experience of being able to work directly with a 5 electrical megawatt closed cycle water reactor at Saxton, Pennsylvania that will supply electricity for a portion of the GPU System. The entire experimental program for this installation will be centered around concepts aimed at significantly reducing the cost of producing nuclear power. These experiments will entail work in almost every phase of reactor development.

Career openings for qualified scientists exist in many areas. Some of these areas are listed below.

PHYSICIST: Capable of independent work in reactor physics, to direct research and development on advanced reactor concepts, or to perform and direct reactor physics and nuclear design work on cores nearer completion.

ENGINEER: To be the Westinghouse representative at the Saxton nuclear power plant. He will be responsible for making necessary tests during a five-year experimental program and will also have the additional responsibility for getting the Westinghouse test instruments connected and operable. This man must have broad reactor engineering experience which includes reactor physics, chemical, thermo and hydraulic design; plant design, instrumentation and control; and experimental test operation. He must be interested in living in a rural region and be able to deal diplomatically with his associates.

SENIOR ENGINEER: Alloy development on reactor materials and fuels with particular emphasis on control rod and cladding materials. M.S. degree in metallurgy with three years experience in reactor materials.

ENGINEER: To perform analyses and specification of fuel cycle requirements for WTR; to perform analyses of experiments to be inserted in the reactor. He must be able to determine reactivity losses associated with fuel depletion and experiments inserted or removed from the reactor. These analyses will include neutron flux perturbation, power production and safety analysis of experiments and their effect on the reactor. Must possess a B.S. in reactor engineering or an M.S. in physics with two years experience in nuclear design of reactors.

ENGINEER OR SCIENTIST: To perform reactor physics calculations on reactor cores which involve problems of the development and application of theoretical methods, founded on basic theory, to technical programs concerned with the design and construction of large power reactors. M.S. degree in physics or nuclear engineering.

SCIENTIST: Involves the mathematical analysis of problems in reactor physics and engineering with emphasis on the development of digital computer programs or adaptation of existing programs to meet special requirements. B.S. degree in mathematics, physics or engineering with emphasis on applied mathematics and experience in digital computer applications.

MGR. PHYSICAL METALLURGY SECTION: The position requires a man well rounded in the fundamentals of physical metallurgy and with 5 to 10 years experience. Must be experienced with the effects of radiation on metals both fuel bearing and non-fuel bearing. The position will also involve stainless steel and carbon steel alloy development and development in the field of other high temperature metals and ceramics such as graphite, beryllia or other ceramics used in the nuclear industries. A strong foundation of physical chemistry is desirable since there will be problems concerning corrosion. Must be able to assist project design engineers in problems regarding the fatigue, creep and brittle fracture of metals and alloys.

If you qualify for any one of the above positions, write immediately to: Mr. C. S. Southard, Westinghouse Atomic Power Division, P. O. Box 355, Dept. X-95, Pittsburgh 30, Pa.

Westinghouse

ATOMIC POWER DIVISION

FIRST IN ATOMIC POWER

Heaven . . .

and

TMC

Pulse Analyzers

CN-110 256-channel Analyzer

404 400-channel Analyzer

"North *Heaven*, U.S.A." was the way our address came out in one of our ads translated for a foreign publication. Before the SEC and our competitors take us to task for claiming unfair competitive advantages, we'll admit we're a completely earthly operation. All over the earth, in fact.

Such international fame and fortune for TMC instruments comes, we think, from the universal appeal of wide usefulness in a single instrument — as exemplified by the CN-110 256-channel analyzer. It has 7 interchangeable plug-in logics, including pulse height, time of flight, pulsed neutron, multi-scaler, mass spectrometer, and coincidence pair. Circuitry is all-transistorized. Analog, binary, octal and decimal readout may be used. Data can be recorded on strip chart or X-Y recorders, printed paper tape, punched paper tape, or punched cards.

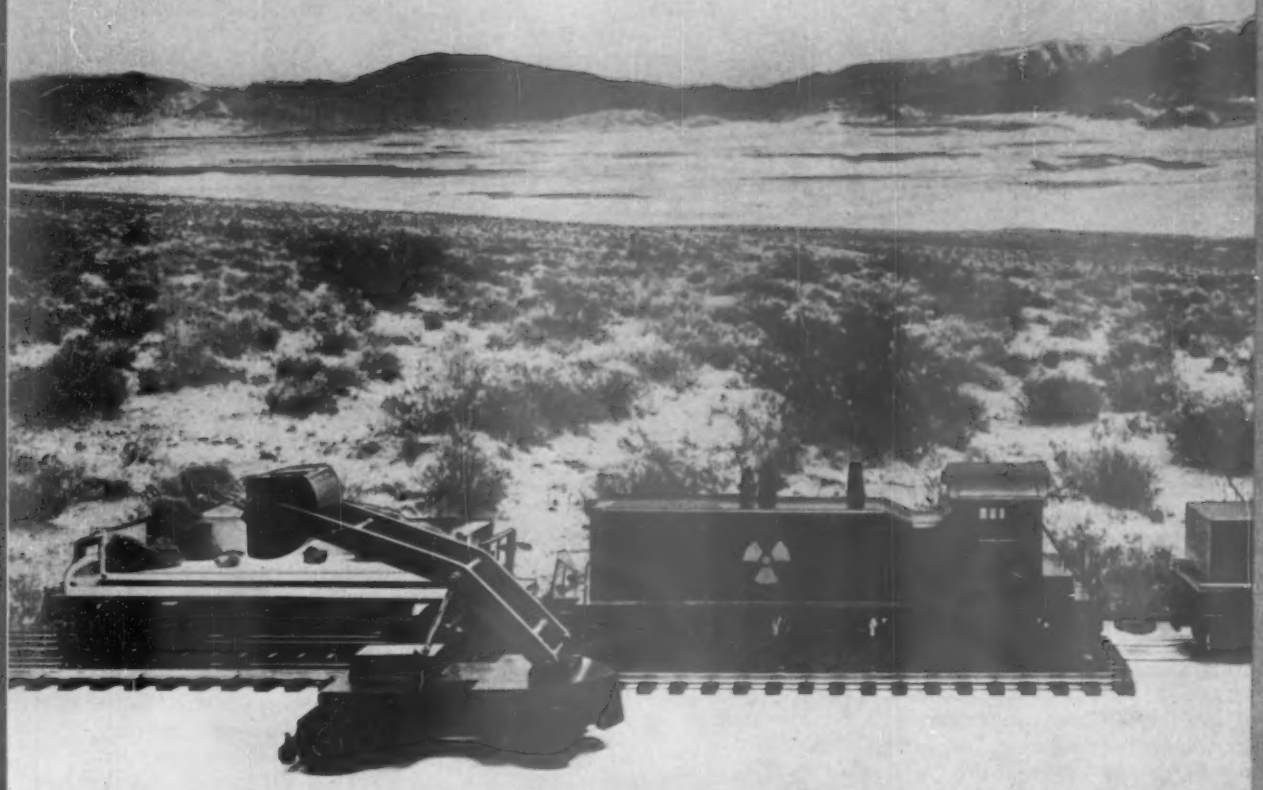
If you don't need an analyzer with this much versatility, but want instead a compact, portable, accurate, 400-channel instrument, the new TMC 404 may be just the thing for you. It has a magnetic core memory that can be used in sub groups of two or four; four separate inputs and associated amplifiers; internal pulse routing circuitry; push-button data transfer and display overlap; power requirements of *only 25 watts;* and provision for readout on a companion TMC Decimal Printer, high speed paper tape punch, strip chart or X-Y recorder, or an IBM electric typewriter.

**Note: The dog is dead . . . he had an unfortunate accident last week when struck by a suddenly swerving policy. (A temporary situation, we hope.)*

Write for literature on TMC instruments . . . to North *Haven*, Conn.

TMC **TECHNICAL MEASUREMENT CORPORATION**
441 WASHINGTON AVE., NORTH HAVEN, CONN. • CE 9-2501

How to handle a nuclear rocket engine



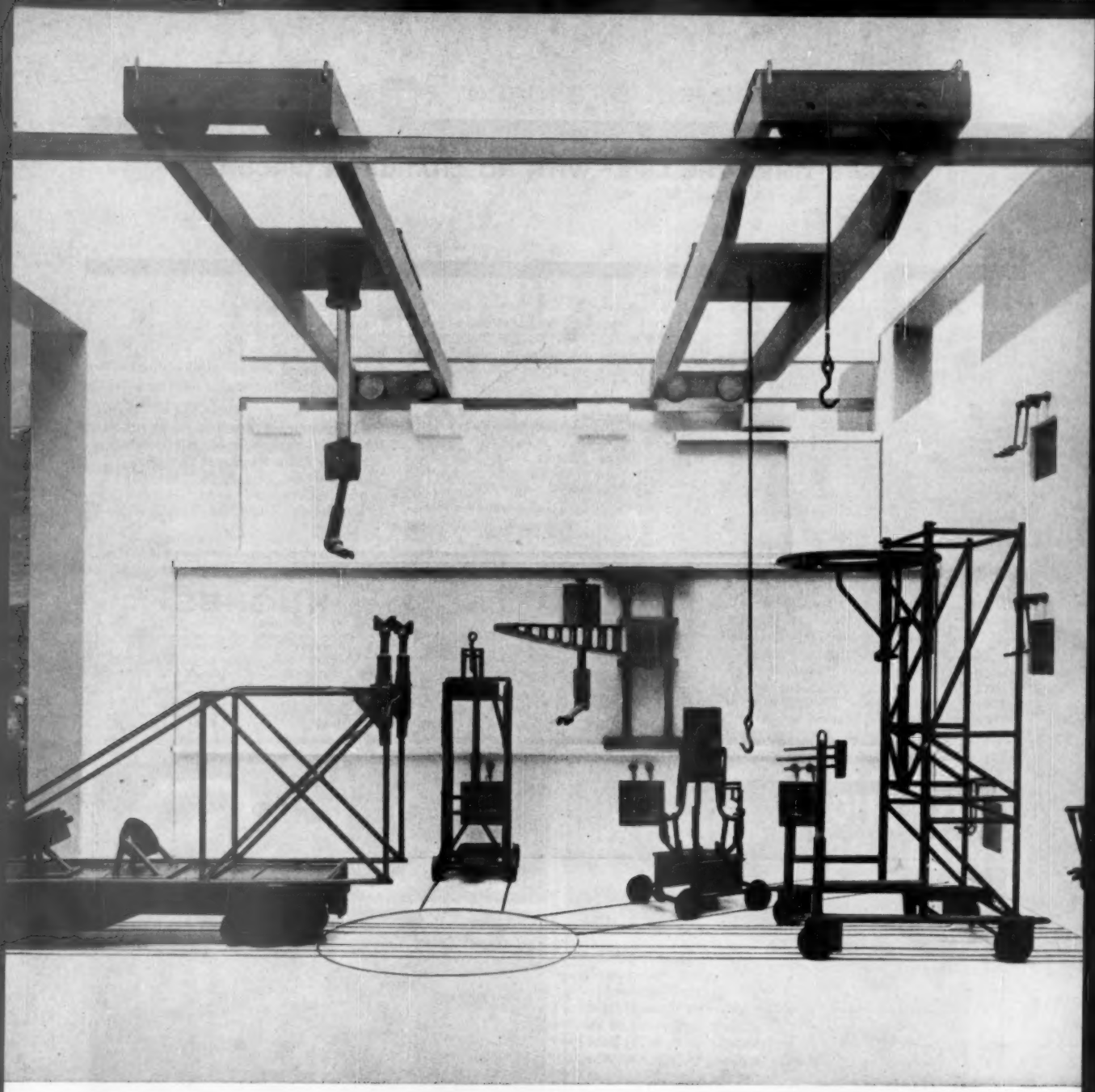
Anticipating the development of nuclear rocket engines, AMF Atomics has *already completed* conceptual and preliminary design work on facilities, procedures and equipment for the fantastically complex (and unique!) remote handling problems that will have to be faced. The equipment you see here can do the following *entirely by remote control:*

...remove an engine from the test stand after static test, put it on the specially-rigged flatcar, transport it to this hot cell, disassemble it into components right down to individual fuel elements, permit comprehensive inspection, cope with damage (for example, mechanical distortion) sustained during test and otherwise handle defective parts and other non-routine problems, and reassemble the entire engine.

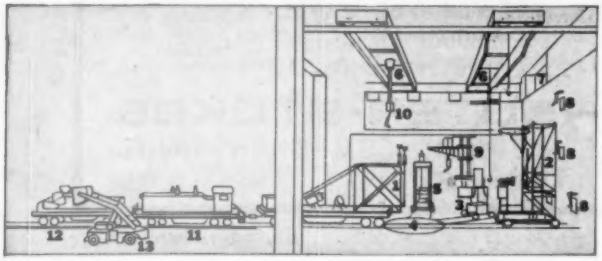
Since the nuclear industry began, AMF Atomics has led the world in research reactor design and construction, fueling and other auxiliary and remote handling equipment. Ingenious machinery is our specialty, growing out of 60 years of AMF experience in solving difficult mechanical problems for industry.

Projects already undertaken by AMF Atomics include fuel and core structure handling equipment for Savannah River and for the AEC's New Production Reactor at Hanford; nuclear aircraft engine handling equipment; remotely controlled vehicles for the U. S. Air Force, and the on-power refueling system for the CANDU Reactor.

Handling stand 1/ on special flatcar brings engine from test area. Note TV camera for operation surveillance. Disassembly/ assembly machines 2/, 3/, 5/, remotely accept and disconnect the various engine components. Note three gauges of track and turntable 4/ which permit machines to move and nest together. Note high capacity overhead cranes 6/ and pass-through 7/ to other parts of building for component delivery to other cells and crane maintenance. Wall mounted 9/ and overhead manipulators 10/ handle some of the heavier operations. Master-slave



manipulators 8/ are strategically located throughout cell area for lighter duty operations. Transfer vehicles include remotely-controlled locomotive 11/ and special flatcar 12/ for handling contaminated components. General purpose, manned shielded vehicle 13/ is used for surveillance, recovery operations, and to make other remote adjustments either at the test stand, disassembly cell, or intermediate areas.



AMF ATOMICS

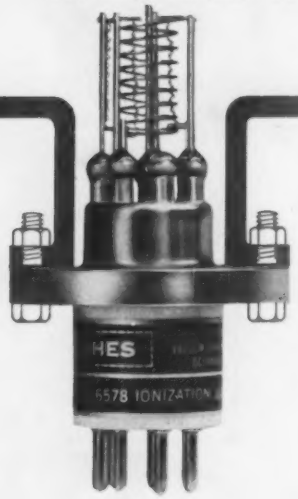
A Division of American Machine and Foundry Company

140 Greenwich Avenue, Greenwich, Connecticut

EXPERIENCE, PERFORMANCE

ACROSS THE BOARD, ACROSS THE WORLD

THREE TIMES THE LIFE—WITH NO CHANGE IN CIRCUITS



Ionization Gauge Tubes ideally suited to your vacuum measurement applications are now offered by Hughes.

Outstanding features include:

- Three filaments to effectively extend life and reduce down time.
- Accurate, reliable, continuous measurement of vacuums to 10^{-9}mm Hg.
- No change in circuitry required for use in your existing vacuum measurement system. (Controls also available.)
- Available nude (as shown): $65.00—or in glass bulb: $30.00—to fit your present system.
- Consistent, dependable performance.

You can be sure of superior performance and long service life from Hughes Vacuum Gauge Tubes supplied with original equipment—or bought as replacement parts.

For additional information on these tubes and controls write: **HUGHES Vacuum Tube Products Division,** 2020 Short St., Oceanside, Calif. For export information, write: Hughes International, Culver City, Calif.

Creating a new world with Electronics

HUGHES

HUGHES AIRCRAFT COMPANY
VACUUM TUBE PRODUCTS DIVISION

INSPECTION PROBLEMS?
This booklet is for you!

This comprehensive, elaborately illustrated booklet provides practical information on the use of the famous A. C. M. I. Borescope in various industries, for the inspection of interior areas or surfaces not otherwise visible—together with full data on the types of Borescope available, and on their care and maintenance. Have you received your copy?

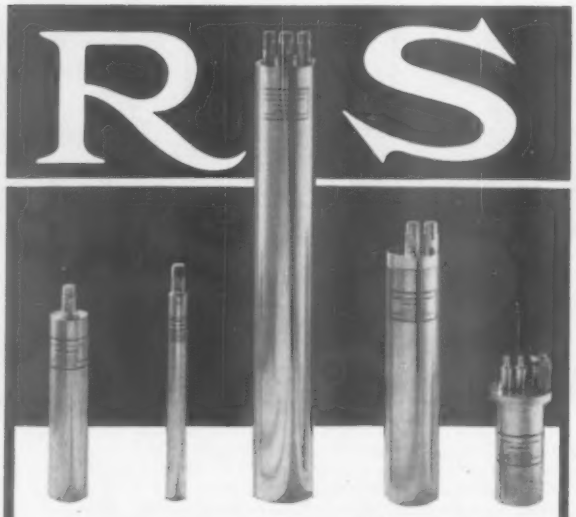
Free on request — *Fill in and mail today*

To *American Cystoscope Makers, Inc.*
8 PELHAM PARKWAY PELHAM MANOR, N. Y.

Gentlemen: Please send me without obligation a copy of your booklet on Borescopes.

Name_____
Firm_____
Address_____
City_____ State_____

R S



At Your Service for **NEUTRON DETECTION**

- Proportional Counters
- Fast Neutron Detectors
- Ionization Chambers
- Fission Counters/Chambers
- Standard Design or to specific need

Inquire also about our Radiation Resistant Cables and Sapphire Metal Windows

REUTER-STOKES
ELECTRONIC COMPONENTS, INC.
2149 Hamilton Ave. Cleveland 14, Ohio

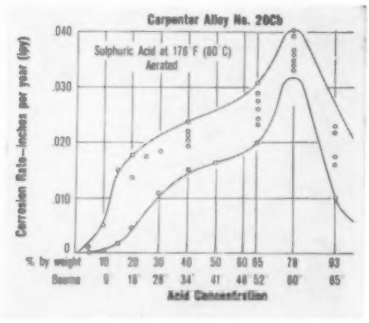
5 extra reasons to consider Carpenter Stainless Steels for your nuclear applications

Quality, uniformity and super-cleanness are obvious requirements for the stainless steels you use. And Carpenter's dedication to exacting standards will more than repay your confidence. But Carpenter goes a step beyond the obvious. Here are a few extra benefits you'll find worth considering.

❶ New developments

One example of Carpenter's nuclear-geared product development program, is stainless type 304 which contains up to 2% of boron 10, an isotope of boron. This alloy was developed especially to provide an effective combination of high neutron absorption and high ductility with good corrosion resistance. This special boron bearing grade of stainless type 304 is being used currently as control rods, "burnable poison" and shielding for nuclear reactors. A technical data sheet on this grade is yours for the asking.

❷ Better corrosion resistance



The wide range of stainless steels available offers you the exact degree of corrosion resistance necessary for almost any corrosive environment. For mild corrodents, Carpenter No. 1 (Type 410) can be used; for extremely severe corrodents such as hot sulphuric acid solutions, Carpenter No. 20Cb should be specified. For other corrodents, one of the many other stainless steels will be the most economical material for you to use.

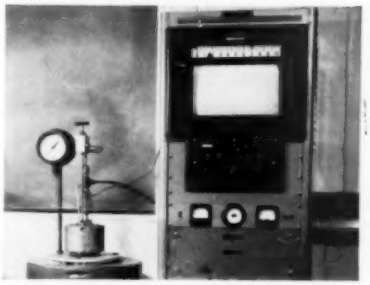
Carpenter No. 20Cb is a special alloy first produced by Carpenter in wrought form. Its excellent resistance to hot sulphuric acid is shown in the chart below, left. For information on its resistance to other corrodents, send for booklet, "Super Corrosion Control".

❸ Improved forgeability

Tough, hard-to-work stainless and heat resisting steels now can be forged to closer tolerances than ever before. Steel waste and rejects can be reduced. This photograph offers proof.

These two forgings were made from the same type stainless steel . . . and forged under identical conditions. The chemical composition of the left-hand disc is within conventional limits. The one on the right shows the result of Carpenter's exclusive balanced analysis. Its chemical composition was precisely adjusted within the specification limits to the balanced analysis which provides optimum hot working properties. For your protection, Carpenter forging grades carry a special label identifying forging quality stainless steel for quality stainless forgings.

❹ Dependable performance



Carpenter Stainless Steels are continually tested and evaluated in the Corrosion Research Center, considered the largest and best equipped of its kind among specialty steel producers. The autoclave pictured here is typical of the equipment used to evaluate materials at high pressures (up to 3000 psi.) and elevated temperatures (up to 750°F). It is used regularly to measure the suitability of stainless and other alloys for nuclear applications.

❺ Technical assistance

This 180-page working data book on stainless and heat resisting steels is typical of the technical help available from Carpenter. It includes descriptions of all grades, properties and characteristics. Also selection help, fabrication tips and useful corrosion tables. Call your Carpenter Representative, or write for a copy. For additional help on specific design or application problems, your Carpenter Representative will be glad to work with you.

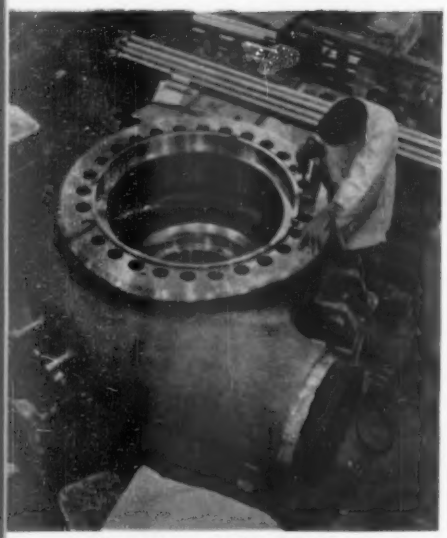
Carpenter steel

you can make it ***consistently*** better with Carpenter Stainless Steels for specialists

The Carpenter Steel Company, Main Office and Mills, Reading, Pa.
Export Dept., Port Washington, N.Y.—"CARSTEELCO"
Alloy Tube Division, Union, N.J.
Webb Wire Division, New Brunswick, N.J.
Carpenter Steel of New England, Inc., Bridgeport, Conn.

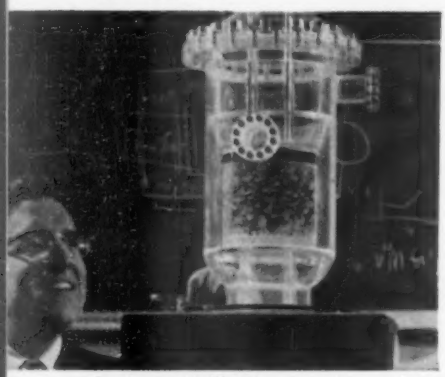
Thousands of Westinghouse people work full time on commercial atomic power

People, facilities and successful experience . . . these are reasons why Westinghouse is the world's leading supplier of nuclear power plants and components.



Westinghouse Quality Control inspector is working on a nine ton stainless steel pump casing at the Atomic Equipment Department in Cheswick, Pa. Department produces canned motor pumps, valves and control rod mechanisms.

Electron Beam Welding of core components is one of the many special skills employed at the Atomic Fuel Department, Cheswick, Pa. Standard products of the department are reactor cores and their components.



Dr. James H. Wright, shown here with an organic moderated fluidized bed reactor model, is also doing important development work on the concept of an integral boiling and superheat reactor (IBSHR).

Westinghouse Engineers, after design, follow through on construction of reactor plants such as this 5,000 kilowatt plant being built at Saxton, Pa., for the Saxton Experimental Corporation. This new reactor will be used with an existing turbine generator at the Pennsylvania Electric Company site.

Westinghouse Testing Reactor facility includes hot cells and metallographic cells for post-irradiation examination of samples. Nuclear fuels and other materials can be tested inside cylindrical fuel elements of reactor core. Chemical, analytical and counting laboratories are used for post-irradiation tests.

Critical Experiment Station at Testing Reactor. This technician is working in the low power test facility used to confirm physics calculations by experiments before exposure in the reactor.

J1-59503

Westinghouse Mathematicians are working out the solution to a nuclear fuel problem at this computer installation in the Atomic Power Department at Forest Hills, Pa.

Dr. W. E. Shoupp, Technical Director of the Atomic Power Department, plays vital role in developing atomic fueled plants to the point where they will be economically competitive with fossil fueled plants in the generation of electric power.

Skilled Machinist is working on the shell and flange for a canned motor pump on a 120" vertical boring mill at the Atomic Equipment Department.

Dr. Joseph C. Danko heads up promising advanced research of the thermoelectric reactor, a potential means of generating electricity directly from fission heat without a turbine-generator unit.

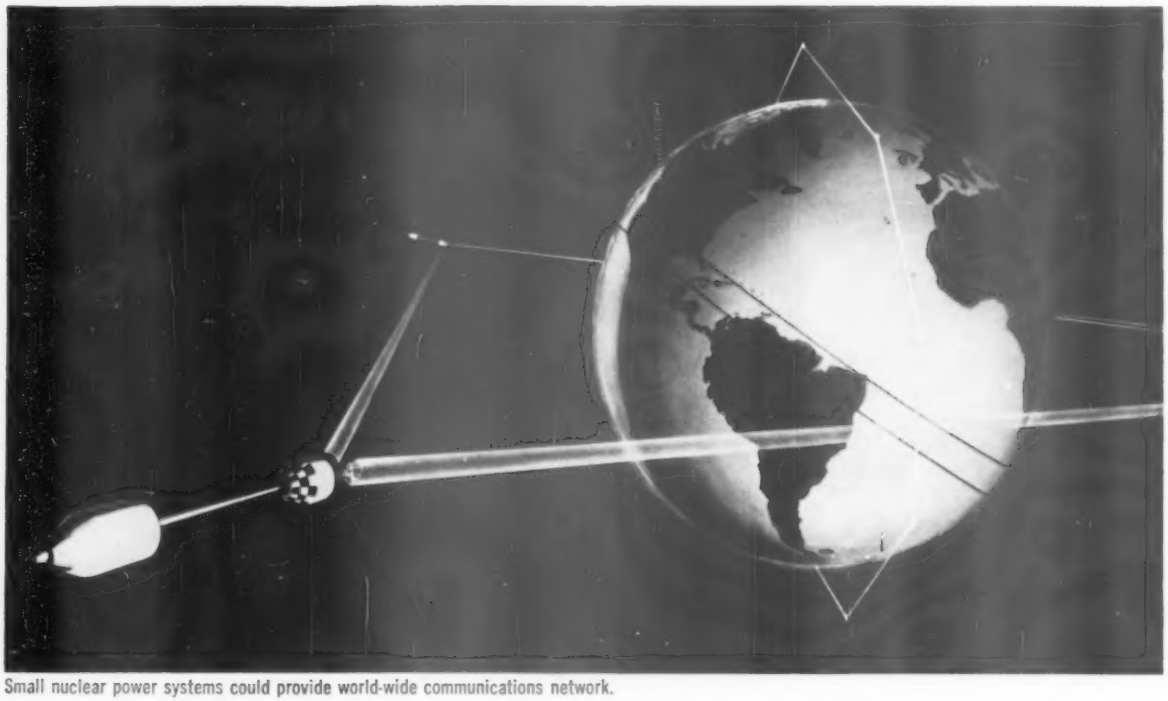
Fuel Assembly Operation at the Atomic Power Department, where facilities are maintained for development of advanced fuel concepts. Technician is working on cage of a fuel assembly.

Dr. Sidney Krasik, Technical Director of Astronuclear Laboratory, works on applications of atomic power in outer space, such as nuclear power propulsion, the nuclear ram jet and auxiliary power plants for space vehicles.

you can be sure . . . if it's

Westinghouse

Westinghouse Electric Corporation
P.O. Box 868, Pittsburgh 30, Pa.



Small nuclear power systems could provide world-wide communications network.

NUCLEAR POWER IN ORBIT

At this moment engineers and scientists at Atomics International are extending the boundaries of present day technology to provide this country with lightweight, long-life auxiliary power systems for outer space applications. These systems must be light in weight, fully automatic, completely reliable... yet must provide thousands of watts of electricity for periods up to one year without maintenance.

We need creative engineers and scientists to help us provide this new source of auxiliary power for outer space.

IMMEDIATE OPPORTUNITIES ARE AVAILABLE IN:

STRESS ANALYSIS. Degree plus five or more years of experience either in thermal stress or dynamic stress resulting from shock and vibration loads in aircraft structures. Responsibilities will entail design support for compact nuclear power plants for space applications, including review of all designs with respect to stresses resulting from thermo gradients and transients, static loadings, and vibrational and shock loadings.

CORE ANALYSIS. Core analysis of compact reactors including both core statics (criticality, reactivity coefficients, control statics) and stability analysis (core transients, amplitude response, interpretation of oscillator and noise measurements).

SHIELDING ANALYSIS. Analysis of thin shield systems using high speed computers. Proposal of experiments to substantiate calculations and analysis of test results. Degree and three to five years experience required including an understanding of Monte Carlo methods.

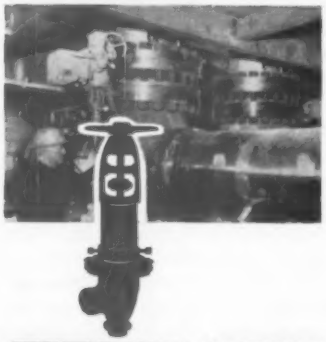
THERMOELECTRIC. Electrical engineer with one or more years experience in the development of thermoelectric equipment to originate and develop advanced, light weight thermoelectric equipment for use with compact nuclear power plants for space and other mobile applications.

HEAT TRANSFER. Senior engineer to be responsible for system engineering studies on the thermal, hydraulic and thermodynamic performance of compact power reactor systems.

For specific details write: Mr. C. G. Newton, Personnel Office, Atomics International, 8900 DeSoto Avenue, Canoga Park, Calif.

ATOMICS INTERNATIONAL
A DIVISION OF NORTH AMERICAN AVIATION, INC.

PUMPS



VALVES

HEAT EXCHANGERS

FOR WATER-COOLED POWER REACTORS

How well future nuclear power plants operate depends heavily on how well we learn from the experience we are amassing today. Reactor-system main pumps, valves and heat exchangers play significant roles in both plant investment and operating costs. Their purchase price can be 10% or more of the total cost of the plant—or 25% of the cost of all reactor-plant equipment. Their influence on operating and maintenance costs is being defined more clearly by plants in operation. This special report offers a picture of what we have learned so far about these components in water-cooled power-reactor systems—and how this experience is influencing the design of equipment for new plants.

Current efforts to improve limited-leakage pumps so they can compete in performance with the more expensive canned pumps, vigorous tries to reduce the cost of reliable canned pumps, the need for larger valves and more dependable relief valves and new data being gathered on the relative merits of Inconel, stainless steel and carbon steel for steam generators—these are some of the key developments to watch.

The path NUCLEONICS followed in gathering information for this report helps explain some things about the field itself. We had the impression last fall that component experience with pressurized- and boiling-water reactors had advanced enough to show substantial feedback in improv-

ing plants. After discussions with companies vitally concerned with water reactors, we decided to probe more deeply into the status of pumps, valves and heat exchangers. We asked 30 system designers, component suppliers and reactor operators what they considered the most significant improvements made in these three components and what further development was needed most. Their opinions helped us to formulate scope outlines and select authors for the articles in this report. Then to learn specifically what pumps, valves and heat exchangers are serving in pressurized-water, boiling-water and aqueous-homogeneous reactor plants (listed in NU, Nov. '60, p. 148), and what operating experience has been with them, we sent detailed questionnaires to the designers or operators of all these plants.

For further information, one of our editors visited the Shippingport, Yankee, EBWR, N. S. Savannah and Commonwealth Edison operators, the designers of a number of other plants and the manufacturing plants of pump, valve and heat-exchanger fabricators. These steps, together with the experience and parallel studies by our authors, make up the input for the report.

We found it difficult to come to grips with the status of reactor pumps, valves and heat exchangers. The problem is the common one of communication. Neither reactor plant designers, fabricators nor operators seem to understand each others' problems and capabilities. Nor do they seem overly aware of what their counterparts are doing in other countries, projects or companies.

Certainly a big reason for this is that each of these men is very busy with his own day-to-day problems. Historically in the nuclear field this has been true—and also historically it *has* been difficult to get frank current information on projects other than the one on which you are working. Certainly governmental information restriction has been a nuclear habit—by some governments more than others and in varying degrees from project to project. But now some companies are joining the act with the viewpoint that they don't want anyone to think that they ever make less than a perfect decision (or product)—or, in effect, ever learn by experience. Certainly there *are* technical areas and times in which discretion is important. But in a field as dynamic as nuclear power, as technically complex in terms of its dependence on the skills of many people and as dependent on the deep financial stakes of industrial firms and taxpayers, more direct exchange of operating data is vital. With utilities weighing whether to make commitments to nuclear power, we need to extract the true economic significance of the operating experience we are gathering from today's plants and today's equipment. Even now, and for some time to come, we can't afford statistically to restrict our data-taking to only one or several of the few plants that are operating. For instance, by considering factors of design, fabrication and operation for all pumps in water-cooled-reactor plants we *can* evaluate the true range of performance and cost that we can expect for future plants. And plant designers and pump suppliers can learn what they must do better. The same applies to valves, heat exchangers and every other component of reactor systems.

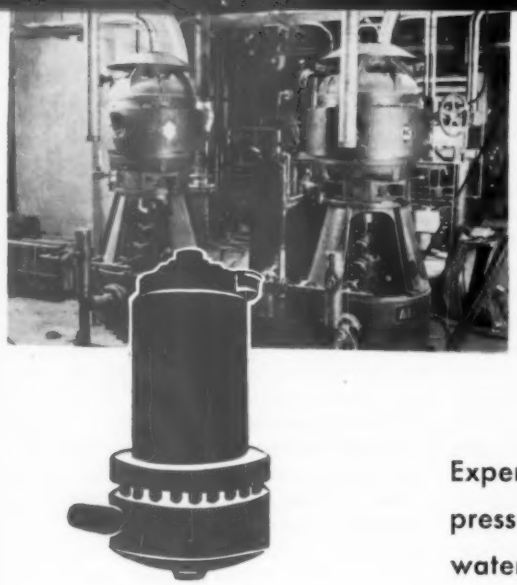
With better interchange of viewpoints all three vitally concerned parties—plant designer, fabricator and operator—can make their own invaluable contributions toward better nuclear power plants. All three parties have a vital interest in better plants. But as of now it takes too long for their experience to feed back into improved plants.

A designer who is trying to choose a new component often complains that the manufacturers don't know enough about how their equipment performs, for instance, under rapid power transients. The designer feels that only a few manufacturers can meet his tight requirements, so he writes a specification that goes into manufacturing process details that "worked last time"—and that will eliminate some of the multitude of bidders from contention. He believes that manufacturers should know more about reactor-system requirements and that operators should tell more about how their equipment performs and what improvements they want.

Equipment manufacturers retort that designers persist in saying precisely *how* to make the equipment rather than adequately describing the operating conditions and performance desired. This drives costs up but doesn't help the fabricator to add his design and fabrication experience to the task. Generally, nuclear-experienced fabricators feel they could give a significant performance guarantee if the reactor system designer would describe the operating conditions and explain the significance of restrictive material, tolerances, cleanliness and reliability specifications. The manufacturer feels that he then could propose a component design he would be willing to guarantee—and then he could review design details with the nuclear system designer. There's one thing about which the fabricator agrees vigorously with the system designer—he gets very little information from the operator on how his and other equipment stands up in service.

The reactor plant operator is on the receiving end of the designer's and fabricator's misjudgments. He's convinced he paid too much for reactor equipment, some of the most conventional of which takes far too much adjustment and maintenance under difficult conditions. He would rather spend more of his time adjusting cheaper versions of the more expensive components. In any case, the operator usually believes the plant designer puts too much attention on unimportant things and too little on some significant items. He sometimes feels that the manufacturer didn't test the equipment adequately and simply neglected key specification points in the belief they weren't worthwhile. Although the operator has acquired valuable on-the-line experience that would help his suppliers do a better job in the future, he usually is too busy with daily problems to tell his suppliers or fellow operators about it. Neither does he find the time to learn what equipment improvements are in the mill, nor what the operators of other reactor plants have done to solve or avoid the same problems he faces.

From any viewpoint the old process of "learning from mistakes" doesn't help amortize nuclear plant costs unless it is put to work. One way to start the gears is for designers, suppliers and operators to talk among themselves about their accomplishments and problems. Only in this way can they hammer out improved plant components, make new developments and resolve problems of initial cost vs maintenance cost. Then nuclear power cost will drop for the benefit of all three parties—and for the power user who ultimately pays the bill.



PUMPS

FOR WATER-COOLED POWER REACTORS

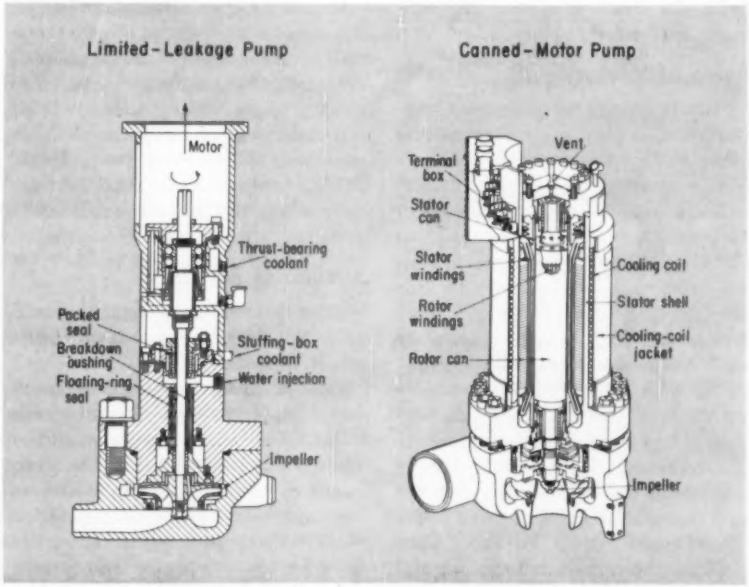
Expensive canned-motor pumps are best, so far, for large pressurized-water plants. For small ones and boiling-water plants, improved shaft seals permit cheaper pumps

MAIN PUMPS for circulating reactor-coolant water in a 300-Mw(e) nuclear power plant cost ~3% of the total cost of the plant. Their driver motors use 2–4% of the electricity the plant generates. They must operate reliably without permitting radioactive water to leak from the system. The direction to take in developing reliable and less expensive pumps depends on experience in operating plants. By considering the types of pumps in use now, how they are standing up, improvements that have been made and others in the development stage, we can see nuclear pump trends and the approaches new plants will take.

Most water-cooled-reactor power plants built so far use zero-leakage canned-motor pumps for circulating the coolant. Such pumps have been developed to be quite reliable. They are likely to continue to find extensive use with ship-propulsion reactors and in the larger and more highly pressurized central-station power plants. Aboard ship radioactive-water leakage is difficult to handle, and suitable seals for large conventional pumps have not been developed. But because conventional pumps can cost 20–50% less and be 10% more efficient than canned pumps, there is a strong incentive to develop tight shaft seals for conventional pumps. Recent progress toward developing such seals is encouraging, but their reliability and freedom from complex auxiliary systems are still questionable. Even so, there is still room for improving the economics of canned pumps. Thus it is evident that both types of pumps have nuclear futures. Where the line is to be drawn will depend on the vigor of efforts to improve either type of pump.

Avoiding Water Leakage

Radioactivity of the coolant is the principal problem that makes reactor-system main pumps differ from their conventional counterparts. To *prevent* hazardous leakage of radioactive water, special "canned pumps" (impeller, motor and shaft are all sealed within the piping system) are used. On the other hand, if *limiting* the leakage is suitable, we can use conventional pumps in which the rotating drive shaft has a special seal around it where it enters the impeller casing (the driver motor is outside). In some such installations the radioactive water that leaks from the special seal is drained off, purified and reinjected into the piping system. In others pure water at higher-than-system pressure is injected through the seal so as to prevent the radioactive water from flowing out. (*Continued*)



Although the radioactivity induced in pure water itself as it passes through the reactor has only a 7-sec half-life, many of the impurities it picks up as it corrodes the piping system become quite radioactive and have much longer half-lives. Several things are done to alleviate the problems this causes. One is to demineralize part of the reactor water continuously. Another is to restrict the corrosiveness of the water by keeping a slight excess of hydrogen in it so that oxidation is reduced. A third step is to make the piping, pump casings and impellers of stainless steel, which corrodes less than carbon steel. (Type 304 stainless steels are preferred since they retain their corrosion layer better than other types and are less costly.) To reduce the amount of contamination that might lodge on the internal surface of pumps and make decontamination and repairs difficult, no cracks, crevices or pits have been permitted on the inside of pump casings or on impellers.

Because of the difficulty and cost of shutting down a nuclear plant, decontaminating areas and making repairs, there is an economic balance between initial cost of equipment and maintenance cost, including reliability. Just what the balance should be for minimum pumping cost is a question whose answer depends on operating experience with various conditions and types of pumps. A consideration of the design features of various pumps in service, their performance, costs and improvements being sought helps to define the direction system designers must take for future plants.

Types of Water Seals

Over the years designers and operators of feed pumps for conventional power stations have faced the problems of sealing against more than a moderate amount of leakage. As water temperatures and pressures rose to 450° F and 350 psi suitable seal designs and materials were evolved. But when pressurized-water reactors were developed pump designers suddenly faced the problem of sealing against leakage of 2,000-psi 600° F water. No conventional seal could do this adequately, particularly since excessive leakage or seal failure would involve radiological safety problems and the need to decontaminate the area before repairs could begin. To avoid these problems the canned-motor pump was developed to the design criterion of zero leakage.

Canned pump seals. No water leaks from a canned-motor pump because the entire pump and driving motor are completely enclosed within pressurized casings—there is no path for leakage since the rotating drive shaft does not penetrate the case.

To keep motor windings dry, the stator and rotor are canned within thin sheets of stainless steel or Inconel. An auxiliary impeller circulates the small amount of water in the 30–50-mil space between the stator and the rotor liners so water lubricates the carbon-graphite journal and thrust bearings and carries away motor heat. This water then passes out of the pump and circulates through a coolant tube wrapped around the motor casing and then goes back into the pump. A pressure-tight casing that surrounds this coolant coil provides a flow channel for the external cooling water. The motor case is bolted and sometimes seal-welded to the pump case. All electrical and cooling-water leads are sealed to the case to prevent any external leakage even if the motor cans inside rupture.

Limited-leakage seals. Seal design has progressed considerably in recent years, but still no conventional seal has been developed for which we can predict definitely the amount of seal leakage, its life expectancy or reliability when used in large main reactor pumps. Leak-off or injection rates are high, and risk of seal failure has prohibited extensive use of limited-leakage pumps. But many seal designers feel that multiple combinations of the mechanical face seal and the floating-ring seal hold great promise. Many tests are being run under reactor conditions to determine seal life, maintenance problems, effects of entrained solids and the tendency of the seal to collect radioactive deposits.

Auxiliaries Required

Most limited-leakage pumps require more auxiliary systems than canned pumps do.

Canned pumps do not need an external supply of high-pressure cooling water. Instead, a small amount of reactor water circulates in the motor casing to lubricate the graphitar bearings and carry motor heat away (at ~150° F) to an integral cooling coil between the two outer casing walls; low-pressure water from the plant service system removes this heat from the casing. Thermocouples in the motor windings and coolant circuit tell the operator that the winding insulation and graphitar bearings are at no more than 200° F, above which they fail. An instrumented vent also is provided in the casing top to remove any gas formed during coolant-chemistry control operations or by radiolytic dissociation of reactor water.

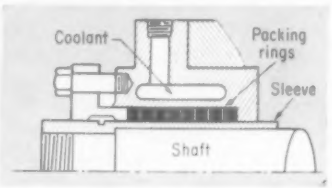
Limited-leakage pumps, on the other hand, nearly all require a high-pressure water injection system and enlarged systems for cleanup demineralization and waste disposal. Inward or outward leakage rates vary from 1 to 50 gpm, depending on pressure, shaft speed and size and on whether a face-type mechanical seal or a pressure-breakdown bushing is used. Since injection water must be 25–50 psi above the pressure of the reactor water, either a small boiler-feed type pump or a reciprocating pump with pulse-damping provisions must be used in the injection system. With controls, either injection system costs about $30,000.

Since increases in normal seal temperature and leakage indicate that abnormal friction and failure have begun, thermocouples and leakage-measuring devices are located in the seal chamber and circuit.

Pumping Capacity

Canned-motor pumps have been built in sizes up to 25,000-gpm for use

Basic Shaft Seals for Limited-Leakage Pumps—1



Packed Stuffing Box has sleeve pressed onto shaft and held by nut; bolts hold packing rings inside stuffing box. With water cooling, this seal has served up to 400° F and 300 psi, but even 1-year life depends on skill of installer and frequent adjustment; packing failure allows large leakage. Although not suitable alone for reactor main pumps, it might be used as a backup on a combination seal

with 2,500-psi 600° F water. Canned pumps for the Southern California Edison plant are being designed for ~45,000 gpm. Limited-leakage pumps of similar hydraulic design have not been built to the same capacity; the upper limit so far is 14,000 gpm with pressures and temperatures the same as in canned-motor units.

Repairs

Limited-leakage pumps require more adjustment and maintenance than canned pumps. But most repairs to limited-leakage pumps can be made at the power-plant site. For instance, the seal or minor parts can be replaced or a spare motor easily can be installed at the site. On the other hand, although canned-pump bearings can be replaced at the site, almost any damage to the rotor or stator cans, windings, shaft, cooling system or pressure-tight casing would require repair at the factory. Further, spare or replacement parts for a canned pump are relatively expensive.

Operating Experience

Over-all, canned pumps have an enviable record of unattended service. A canned pump in the boiler circulation system at the Possum Point Station (Virginia Electric Power Co.) has operated for more than 35,000 hours with no servicing at all. Among the more than 1,000 canned pumps operating, there have been only about a dozen failures. Of these, three have occurred in one loop at the Shippingport plant.

Shippingport. About two weeks after Shippingport began operating in 1958, one pump failed because of unforeseen expansion problems. Its replacement was removed when a bearing failed. The can of the second replacement pump failed when gas accumulated in the gap and caused over-heating. The fact that this particular loop has been the input for water-chemistry control operations at Shippingport might have been a contributing factor. Operators now take care during chemistry-control steps to avoid introducing gas bubbles to the system; pump makers are incorporating gas detectors and vents in new canned-pump designs. The other three canned pumps at Shippingport have operated faultlessly for three years.

NRTS. When a pump in a propulsion-prototype reactor system at the National Reactor Testing Station in Idaho was opened and examined routinely, the operators noticed that the retaining nut on the impeller had dropped off. Fortunately, the impeller itself was still on the shaft. Standard procedure now is to weld all impeller fasteners in place.

Dresden, Yankee. There have been some minor pump problems during initial operation of several plants. At Dresden the flange-seals had to be tightened carefully to stop a small amount of seepage; one had to be seal-welded. At Yankee the flange joints leaked with the original hard nickel gaskets in place; tightening did not solve the problem but did deform the flanges about 0.012 in. It took two weeks to remove the pumps and reface the flanges. The problem could have been avoided by seal-welding the closure, but this would have made subsequent maintenance work more difficult. If the bolts are tightened fully when cold, as temperature rises the flange bolts apparently exert linear and bending forces that load the flanges above their yield stress. Replacement copper gaskets solved the leakage problem at first, but they also leaked when system temperature and pressure were cycled between ambient and operating levels. Yankee has found that the pumps can be operated without seal-welding and without leakage by not tightening the flange bolts as much as had been recommended and by bringing the system to 500° F before raising pressure to 2,000 psi—and by reducing system pressure before reducing temperature. Otherwise, the four Yankee pumps have operated very satisfactorily for well over 5,300 hr.

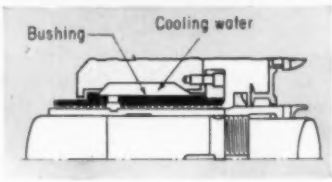
Halden, Spert-3. The small canned pump that circulates water in the Halden plant has performed very satisfactorily during the ~12 months it has operated since it was installed in June, 1958. To prevent air entrapment that could cause local overheating or bearing trouble, operators vent the pump carefully before starting it after long shutdown periods. The four canned pumps in the Spert-3 plant (installed September, 1958) have not been shut down for repairs of any kind. When the Spert-3 plant is shut down routine maintenance involves rotating the pumps daily and keeping the bearings covered with water.

HRE-1, HRE-2. Both these experimental homogeneous reactors have used single small canned pumps for circulating the aqueous fluid fuel; no routine maintenance was performed on these pumps. Generally, operators used remote-handling methods to replace a faulty pump with a spare. During the 15 months HRE-1 operated after the pump was installed in January, 1952, there were four pump failures—three electrical (the motor was under-designed for the service encountered) and one mechanical (after the cracked bearings were replaced the pump was put back in service).

HRE-2 pumps have failed twice in the 20 months the system has operated since the pump was installed in October, 1956. When an electrical lead burned or broke, the operators made repairs remotely with the pump still in place. The other failure occurred during abnormal operating conditions—the titanium impeller and wear rings rubbed against each other and ignited while pumping highly oxygenated water (to avoid a recurrence, the pump was replaced with one having a stainless-steel impeller). Apparently, neither failure can be attributed to faulty design of the pump as such.

Limited-leakage pumps. Nuclear experience with suitably leakage-limited pumps has been confined to units of less than about 10,000 gpm handling water pressures less than 1,200 psi. As in conventional plants, thrust bearings and seals have required periodic adjustment and occasional replacement (which can be done at the site within a short time). (*Continued*)

Basic Shaft Seals for Limited-Leakage Pumps—2



Labyrinth Seals consist of thin strips attached to the housing or shaft as dam-like restrictions to reduce flow. Clearances between moving parts normally are 0.010–0.020 in. so as to avoid rubbing when shaft distorts from thermal expansion and deflects dynamically; thus too many stages would be needed to seal reactor main coolant pumps adequately. Labyrinth seals might be used in combination with other seals

In the four months that the two mechanical-seal circulation pumps at the Vallecitos Boiling Water Reactor have operated since they were installed in March 1960, there have been two shutdowns due to pump troubles. When cooling water ceased to flow to the pump bearings they overheated; when the temperature alarm also failed and did not warn the operator of the trouble, the bearing itself failed (a new type of alarm is being installed). The second pump was shut down when water accumulated in the oil that lubricates the turbine drive (an electric motor drives the other pump). A faulty ejector system caused the problem. After the turbine was dismantled and cleaned, the VBWR operators modified the system to cool the circulating ejector water. Routine maintenance of the VBWR pumps mainly involves lubrication, but the controls for the seal-water-injection system and for the turbine driver are checked and calibrated periodically.

In six months of operation since two mechanical-seal pumps were installed on the Plutonium Recycle Test Reactor in October, 1960, pump troubles on three occasions have caused the operators to shut down the pumps. During development testing, the operators found the high-pressure mechanical seals were wearing excessively when the pump rotating assembly (including 2,400-lb flywheel) vibrated more than 1 mil. The solution entailed closer fits at bearings, impeller and flywheel bores along with careful dynamic balancing of the rotating assembly.

When unstable thrust conditions at full operating pressures unloaded the thrust bearings on the PRTR pumps, a "floating" condition permitted ~3-mil vibration, which would damage the seals. The operators solved the problem by using a 2,000-lb spring loading to add downthrust to the rotating assembly.

Pump Trends

Beyond improvements in pumps themselves, nuclear plant designers are striving to reduce the need for pumps through more reliance on equipment layout that promotes natural-convection circulation of reactor coolant. For instance, it takes less pumping power to circulate water through high vertical steam generators than through low horizontal generators. Development of the Natural Circulation Reactor could eliminate the need for main coolant pumps. Another trend is to have auxiliary pumps serve dual purposes—for instance, the Yankee low-pressure surge tank cooling pump also helps cool the shutdown reactor—so fewer pumps are needed per plant.

A broadly held view is that limited-leakage pumps, because of their lower cost, will replace canned pumps. To accomplish this a number of laboratories are working to develop better shaft seals. But devotees of presently reliable canned pumps point out that an injection-seal or a leakage-disposal system adds to the complexity and cost of limited-leakage pumps. They further point out that even if successful limited-leakage seals are developed they will require more adjustment and maintenance than a canned pump does. They feel that reactor trends work against successful broad nuclear use of limited-leakage pumps. Some of these reactor trends are: (a) boiling-water-reactor pressures are rising from 600 psi to 1,000–1,250 psi and pressurized-water-reactor pressures are rising from 1,200–2,000 psi to 2,200–2,500 psi, (b) reactor outputs and required pump sizes are increasing from 50–100 Mw(e) and 12,000–24,000 gpm to 300–400 Mw(e) and 40,000 gpm (per pump in each loop of a 4-loop system). The Yankee canned pumps have 142% the capacity of the 16,700-gpm Shippingport pumps and the pumps planned for the Southern California Edison plant will nearly double this again.

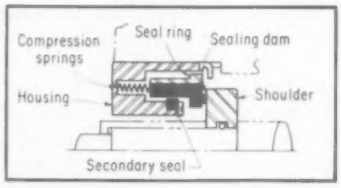
Experience with nuclear pumps has led to refinements that bring economies and improve performance. There have been few or no maintenance problems with radioactive-crud deposition. So plant designers now are less concerned with the surface finish on pumps, particularly the outside surfaces. When designers required the wetted surfaces of both casings and impellers to be smooth to 125 rms or better, lengthy grinding and polishing operations were needed. Recent specifications permit surfaces as rough as 250 rms (for comparison, commercial-pump castings, on which no particular finish is specified, are about 400–500 rms) and many require only a satisfactory radiograph and dye-penetrant inspection for cracks and defects that might lead to pressure failures. Further, in keeping with the growing interest in assuring reliable performance rather than relying on indirect tests, there is expectation that casting techniques will improve to the point that casting inspection can be limited to a pressure test.

For canned pumps, improvements include better graphitar (graphite and carbon held together by an organic binder) formulations for bearings, better can materials (stainless steel has been replaced by Inconel, which has superior corrosion resistance and electrical properties), cans are thinner (15–17 mils rather than 20–50), and hydraulic performance is being stepped up by replacing the diffuser by a smaller guide-vane assembly and by combining the check valve with the pump. Potted windings also are an improvement and there are indications that cans now can be taken off the rotor, thus lowering cost and improving efficiency. As more nuclear plants that use canned pumps are built pump production cost is coming down. Design standardization also will help in this regard (for instance, although their impellers and volutes are different, the canned motors in the Yankee and Indian Point pumps are the same). The increasing use of canned pumps in conventional power plants also is helping to lower canned-pump costs—due mainly to larger production rates, but also because pumps in these plants use cheaper materials (carbon-steel impellers and volutes) and less stringent inspection standards.

Costs

Canned-motor pumps cost 40–100% more than limited-leakage pumps,

Basic Shaft Seals for Limited-Leakage Pumps—3



Face-Type Seal (also called contact or mechanical seal) is used on high-pressure boiler feed pumps. Primary sealing takes place on face where seal ring fastened to stationary housing contacts shoulder on shaft. This type of seal, when arranged in multiples and in combination with other types, holds greatest potential for reactor main-coolant pumps of the limited-leakage type

largely because of the high cost of the special electric motor (60–80% of the total cost). For instance, cost comparisons have been made for an all-stainless-steel pump with a 6–7 in. shaft that moves 40,000 gpm of 625° F 2,500-psi water with a total dynamic head of 150 ft and a net positive suction head (NPSH) of 30 ft. A canned pump to do this would cost ~$450,000 to build, not including ~$250,000 for designing and testing the first one. On the other hand, a limited-leakage pump probably would cost ~$250,000 after a successful seal is developed; some contingency would be added to this for enlarged demineralization and waste-disposal equipment to handle contaminated water if the seal should fail. Also, ~$30,000 would be added if an injection system is needed. For either pump ~$10,000 would be needed for installation and initial adjustments, although the limited-leakage pump might require more if the seal or auxiliaries are complex. Thus, a canned pump might cost $460,000 and a limited-leakage pump might cost $290,000 or more installed (including an injection system but neglecting additional waste disposal and demineralization provisions and seal development costs; seal development might cost $2–3-million). This gives a difference of $150,000 per pump.

Over-all efficiency of large canned pumps usually is between 60 and 75%; limited-leakage pumps are ~75–81% efficient, depending on losses due to seal friction and water injection. If we assume a 10% difference in efficiencies, a canned pump handling 40,000 gpm of 600° F water at 150 ft TDH would require ~150 kw(e) more input power than a limited-leakage pump in similar service; this would involve $15,000 for plant enlargement [at $100/kw(e)]. With a 90% plant factor, 28% cycle thermal efficiency and fuel costing 30¢/million Btu, the extra annual fuel cost per canned pump is $4,525; capitalized at 12% this is equivalent to $37,000.

On these bases a four-pump reactor system using canned pumps would cost a total of $812,200 more than a similar reactor system using limited-leakage pumps [4(150,000 + 15,000 + 37,000) = 812,200]. Against this difference must be charged the larger decontamination and cleanup water demineralization and waste-disposal equipment needed for a plant using limited-leakage pumps. Differences in installation, startup, maintenance and downtime costs also should be factored in, as perhaps should the costs of developing a usable seal. Also, the cost of a canned pump conceivably could drop as low as $350,000 if development attention is turned to reducing cost and if canned pumps continue to find increasing use in conventional as well as nuclear power plants.

Characteristics of Circulating and Feed Pumps in 250-Mw(e) Power Plants

Parameter	*Circulating pumps*		*Feed pumps*	
	Nuclear plant	*Fossil plant*	*Nuclear plant*	*Fossil plant*
Total water flow (gpm)	128,000	28,000	6,400	4,200
Capacity/pump (gpm)	32,000	7,000	3,200	2,100
Suction pressure (psi)	1,950	2,600	260	100
Suction temperature (°F)	580	674	375	338
TDH (ft)	150	125	2,400	6,000
Discharge pressure (psi)	1,995	2,630	1,170	2,900
BHP/pump	1,150	175	2,250	3,800
Total BHP	4,600	700	4,500	7,600

Improvements Needed

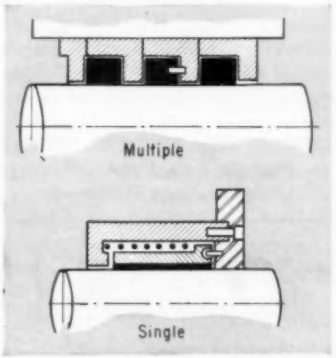
Development of reliable large canned-motor pumps has made high-output nuclear power plants technologically practical. Tighter and larger seals are needed to give the attractive economies of limited-leakage pumps meaning for large power-reactor service. For either pump type, development of less expensive materials and inspection standards could reduce costs.

Inspection standards. Ultraconservative specifications are sometimes justifiable for pumps to be used aboard ship where absolute reliability of operation is essential. But in a utility power station it is practical to shut down the plant for occasional repairs without compromising safety. Commercially oriented inspection standards could reduce nuclear pump costs 10–20%; manufacturers say that nuclear-grade castings cost 30–50% more than commercial-grade castings.

At present, any flaw detected by x-ray or dye-penetrant inspection of a pump casting must be ground or chipped out, filled with weld metal, ground and retested. If we could rely on a hydrostatic test rather than on many expensive indirect examinations, more reliable pump castings might be produced at less cost. Before we can do this we need to learn the actual performance or reliability value of the present conservative standards, perhaps by comparing pressure tests of castings having known defects (internal shrinkage, surface cracks, etc.) with pressure tests on castings that meet conservative nuclear standards.

Alternate materials. To minimize the accumulation of radioactive corrosion products in the water, components in most reactors built so far have been of stainless steel or of stainless-clad steel. Cost could be reduced significantly if low-chrome alloys or carbon-steel could be used or if stainless-clad materials were to replace all-stainless pump components (a canned

Basic Shaft Seals for Limited-Leakage Pumps—4



Floating-Bushing Seal consists of close-fitting sleeve (~0.0015 in. radial clearance per inch of shaft diameter) within which shaft rotates. Floating characteristic of bushing permits fairly free motion that avoids effects of rubbing as shaft moves and deflects. Where large water pressures are involved several bushings or rings can be used in series; since each short ring moves independently of the others, considerable shaft and housing deflections can be accomodated

pump having carbon-steel parts costs 15–30% less than an all-stainless unit). To this end, operators generally feel they can control water chemistry more closely so that cheaper materials can be used in pumps and other reactor equipment.

Operating experience with the carbon steel piping systems in Hanford's New Production Reactor, in the Heavy Water Components Test Reactor (HWCTR) at the Savannah River plant and with the carbon-steel loop in one of the propulsion-reactor prototypes at NRTS will help to clarify the extent to which corrosion-product radioactivity and plate-out on heat-transfer surfaces hinders reactor operation.

On Limited-Leakage Pumps

Use of injection seals can solve the radioactive-water leakage problem but at the expense of a costly and complex auxiliary system that introduces cold water into the reactor system. Thus there is a cost incentive to develop tighter, larger and more reliable mechanical seals to restrict leakage to as little as 50–100 cm³/hr. To boost the development work above the level that pump manufacturers can support purely on the basis of current sales volume, AEC has initiated several seal-development programs.

In heavy-water-reactor programs, both Hanford (PRTR project) and Savannah River (HWCTR project) are working to perfect mechanical seals. Hanford is using a Byron-Jackson limited-leakage pump like the two on PRTR to test various seals that do not need water injection. In a broader program of pump-seal development, du Pont at Savannah River has progressed in model tests from 1-in. to 3-in. shafts.

Face-type seals. Mechanical seals are being developed by Bingham Pump Co., Byron Jackson Pumps, Inc., Peerless Pump and Crane Packing Co. All are testing to 3,600 rpm and 2,500 psi. The Peerless development program uses four face-type seals arranged in two stages of pressure reduction with either internal or external bypasses; with 500° F water and a 4½-in. shaft, leakage is only 1–2 gpm. The Bingham seal on a 4⅝-in.-diameter shaft, consists of a single face-type seal preceded by a throttle bushing that limits injection into the casing to only 1–2 gal/hr when the system is handling 1,600-psi 550° F water. Without water injection, a series of face-type mechanical seals (with self-adjusting pressure distribution) on a 2-in. shaft at Byron Jackson holds leakage of 1,500-psi ambient-temperature water to only 10 gal/hr. Crane's face-type seal on a 4⅜-in. shaft holds leakage of 300° F 2,500-psi water well under 1 gpm; an external heat exchanger removes heat generated by the seal.

For nuclear primary-system pumps, Worthington Corp. is developing a new type of seal that will not pop open or wear excessively when a single seal is used to give a 2,000–2,400-psi pressure reduction (even so, it will be backed up by a 50–100-psi regular face-type seal that keeps water from escaping). At first glance the new seal seems similar to a conventional face-type seal, but it is built and operates fundamentally differently; some parts operate on principles normally associated with hydrodynamic thrust bearings. Between the stationary and rotating parts a predetermined fluid-film thickness is maintained to assure a continuous hydrodynamic lubrication of the co-acting surfaces. The operator can vary film thickness by an external orifice that meters leakage. Tests with a 1¾ in.-diameter shaft seal up to 2,000–2,500-psi and 3,600 rpm show leakages approaching 1 gal/hr.

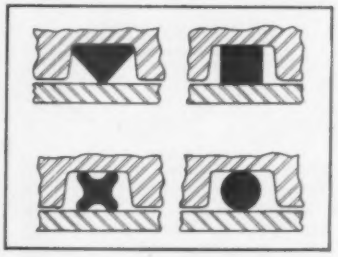
To develop a seal that will limit 650° F 2,500-psi water leakage from a commercial reactor to 1–5 gal/hr,

Major Pumps in a Hypothetical 300-Mw(e) Nuclear Power Plant

Service	*Number*	*Capacity, each (gpm)*	*Suction pressure (psi)*	*TDH (ft)*	*Materials**
Reactor portion of plant					
Primary-coolant circulation	4	{bwr: 25,000 / pwr: 40,000}	{1,050 / 2,100}	125	ss-ss
Cleanup demineralizer circulation	1	400	{bwr: 1,050 / pwr: 2,100}	150	ss-ss
Gland and seal	2	100	Atmos.	{bwr: 1,100 psi / pwr: 2,150 psi}	ss-ss
Decay-heat removal	2	3,000	300	100	ss-ss
Reactor-core spray	2	600	Atmos.	600	ss-ss
Post-incident spray	2	1,000	Atmos.	150	Fe-Br
Turbine-generator portion of plant					
Condenser circulation	2†	{80,000–100,000 (river) / 60,000–80,000 (tower)}		{35–50 / 60–80}	Fe-Br
Condensate	2†	4,500	1.5" Hg	350	Fe-Br
Condensate transfer	2	400	Atmos.	125	Fe-Br
Condensate recycle	1	500	150	100	Fe-Br
Demineralized-water transfer	1	500	Atmos.	125	ss-ss
Reactor/steam-generator feed	2†	4,500	80	3,400	Fs-Br
Heater drain	2	1,500	7 psia	40	Fe-Br
Fuel-storage pool	2	500	Atmos.	125	Fe-Br
Closed system cooling	2	3,000	Atmos.	100	Fe-Br
Utility cooling water	2	4,000	Atmos.	125	Fe-Br
Fire water	2‡	2,000	Atmos.	400	Fe-Br
Well water	2	3,000	Atmos.	Variable	Fe-Br

* First symbol applies to casing, second symbol is impeller; ss = stainless steel, Fe = cast iron, Fs = fabricated steel, Br = bronze. † One is for backup. ‡ One is engine driven.

Basic Shaft Seals for Limited-Leakage Pumps—5



Elastomeric Ring packings of various shapes are often used as nonrotating secondary seals on mechanical-seal assembles, although by themselves they are not leaktight enough for reactor main-coolant pumps. These ring seals are made of rubber, teflon, nitron A or other similar materials

How Reactor Type Affects Primary-Pump Selection

Boiling-water-reactor main coolant pumps operate with suction pressures of less than 1,000–1,200 psi, so casing and seal design are not as difficult as in pressurized-water-reactor pumps. But with the fluid pumped at saturation temperature and pressure, the net positive suction head ("NPSH"—the water pressure required on the suction of a pump in excess of saturation pressure so as to prevent flashing at the impeller) is only the difference in height between the coolant-water level and the pump suction; thus the pump must be installed in the lower part of the plant.

Although coolant can be circulated through boiling-water-reactor systems by natural convection alone (a "direct cycle"), forced circulation of 25–35% of the 550° F reactor water through an intermediate steam generator raises the thermal output of the core and increases cycle efficiency to ~30% (the 450-psi saturated steam produced is directed to a low-pressure admission point on the turbine). Since pressure losses in the primary circuit are unlikely to exceed 125 ft, the primary circulation pump needs only a single stage. But if a separate or integral superheater is used, the reactor feed pump must develop an extra pressure of 50–125 psi to overcome the pressure drop in the superheater.

The boiling-water-reactor condensate and feedwater cycle starts with a deaerating condenser that removes residual radioactive gases not previously disposed of by the turbine-gland steam exhauster. The condensate-pump discharge pressure must overcome all condensate-system head losses and give the reactor feed pump sufficient NPSH under all potential transient conditions. Thus the reactor-feed-pump total dynamic head is the difference between its required discharge pressure and the available suction-side NPSH.

Pressurized-water-reactor main coolant pumps operate with suction pressures as high as 2,000–2,500 psi. Since these pumps circulate all the reactor coolant, they generally are larger than boiling-water reactor pumps, which circulate only 25–35% of the reactor coolant. Thus pump sealing is more of a problem in these larger and more pressurized pumps. But a pressurized-water-reactor coolant system operates at several hundred psi above saturation pressure, so there is little chance of the water flashing in the pump impeller. Thus the NPSH problem is so much less than in a boiling-water-reactor system that the pumps can be installed close to the midpoint elevation.

Most heavy-water-cooled and homogeneous reactors operate as pressurized-water reactors, so their pump characteristics are similar.

Pumps on the secondary or steam side of a pressurized-water-reactor nuclear plant are similar to their counterparts in fossil-fueled steam plants; they have relatively moderate capacities but high total dynamic and discharge heads.

Heavy-water-cooled-reactor main coolant pumps have seals that minimize leakage since heavy water costs $14–28/lb. Also, uncontained leakage of heavy water is both a radioactive and a toxic hazard since neutrons convert deuterium to tritium.

Homogeneous-reactor main coolant pumps are always of the canned-motor type so as to prevent any leakage of the highly radioactive aqueous fuel (uranyl sulphate—UO_2SO_4—dissolved in water or heavy water, or UO_2 dissolved in phosphoric acid—H_3PO_4).

Worthington is extending its studies of this new type seal in another government-sponsored program. Model seals are being used for preliminary tests; by 1963 Worthington expects to have developed and tested a 6–7-in.-diameter seal for installation in a 40,000-gpm reactor-coolant circulating pump that develops 250 ft total dynamic head.

Other seal types. Byron Jackson is developing linear-breakdown bushings. Leakage of 3,000-psi 600° F water from an 1,800-rpm 6-in. shaft is about 75 gpm at present. Primarily for boiler feedpump service at 4,400 psi and 570° F, Ingersoll-Rand Co. is developing a pump seal consisting of numerous floating rings preceded by an initial throttle bushing; it has several stages of water injection for cooling and lubrication. Allis-Chalmers also is developing floating-ring seals.

Even with these accomplishments on seal-development programs, there is no certainty that satisfactorily leaktight seals can be developed for the big pumps needed for large pressurized nuclear plants. Thus there remain strong reasons for continuing development of canned pumps.

On Canned Pumps

Reliable canned pumps were developed originally for military propulsion reactors. Some observers feel that except for size modifications or refinements needed for specific projects, too little effort is being devoted to cutting the cost or boosting the efficiency of canned pumps. Liner, bearing, closure and shell improvements could help, as might eliminating gases and development of a satisfactory wet motor.

Liner. Canned motors are 64–85% efficient; large conventional motors are 92–95% efficient. Most of the difference (7–15%) is due to hysteresis and induced-current losses in the canning material (another 7% is lost in fluid rotation and 3% is lost because of the long narrow motor used to reduce the thickness of the pressure casing). Substitution of Inconel for stainless steel and reduction of liner thickness from 50 mils to 15 mils has raised canned-pump efficiency. Further improvements could result from developing Hastelloy liners (2–3%). Metallurgical improvements that would permit still thinner liners would be helpful as long as reliability does not suffer. Nonmetallic canning materials might be worthwhile. Manufacturing refinements that would permit a smaller gap would reduce fluid losses.

Bearings. The water-lubricated thrust and journal bearings in most canned pumps are made of graphitar. It is something of an art to make these bearings satisfactory for service at more than 300° F (the binder breaks down). A less touchy and more reliable bearing material is needed.

Wet motors. Although motors in which water contacts the motor windings have operated satisfactorily in boiler circulating service, contamination might cause a maintenance problem in nuclear service. The extent of this problem and the effects of radiation on the insulation should be determined.

BIBLIOGRAPHY

1. H. R. Kosmata. New Hanford production reactor uses carbon steel, NUCLEONICS **19**, No. 3, 106 (1961)
2. P. A. Scott. PRTR mechanical seal pump operating experience for period September, 1959 through August, 1960, HW-65724 (1960)
3. Power reactors and experiments the world around, NUCLEONICS **18**, No. 11, 148 (1960).
4. F. L. Speed. Mechanical pumps and circulators, *Nuclear Power* **7**, 277 (1957)

Main Pumps in Water-Cooled

Reactor	Date pumps installed	Service (~mo.)	No. loops and pumps	Function	Performance (per pump)								Pump type
					Capacity (gpm)	TDH† (ft)	Suction (psig)	Suction (°F)	Suction (NPSH, ft)‡	Speed (rpm)	Horsepower Brake/motor	Efficiency (~%)	
Pressurized-Water-Cooled Power Reactors													
Yankee	5/60	9	4	Circulation	23,700	236	1,950	500	2,020/3,720	1,800	?/1,850	62	Canned-motor
Indian Point	?	0	4 loops 8 pumps	Circulation	16,000	356	1,434	480	90/2,780	1,800	?/1,720	68	Canned-motor
N. S. Savannah	3/60	0	2 loops 4 pumps	Circulation	5,000; 2,500	202; 50.5	1,713	70–495	225; 56/varies	3,600; 1,800	?/300; 37.5	62; 60	Canned-motor
NPD	?	0	1 loop 2 pumps§	Circulation	6,000	400	1,004	485	1,070/2,300	1,800	640/800	78	Limited-leakage
CANDU	(~63)	0	1 loop 8 pumps§	Circulation	6,800	522	1,265	480	90/1,836	1,750	968/1,250	77	Limited-leakage
R3/Adam	(10/61)	0	4	Circulation	3,700	140	460	401	45/450	2,950	175/255	63	Canned-motor
APPR-1 (SM-1)	1/57	48	1§	Circulation	4,000	30	1,190	431	?/2,340	1,730	?/50	50	Canned-motor
APPR-1A (SM-1A)	11/60	0.1	1§	Circulation	7,150	57	1,190	423	38/2,440	1,180	107/125	54	Canned-motor
PM-1	(8/61)	0	1	Circulation	2,125	86	1,300	445	60/?	1,750	?/55	71	Canned-motor
PM-2A	8/60	2	1	Circulation	4,240	50	1,750	500	30/2,560	1,750	?/65	64	Canned-motor
PM-3A	(8/61)	0	1	Circulation	2,200	95	1,300	445	60/?	1,750	?/55	71	Canned-motor
NPR	(?)	0	8	Circulation	?	?	?	?	?	3,600	?/≤9,100	56	Limited-leakage
PRTR	10/60	6	1 loop 2 pumps§	Circulation	4,200; 1,400	290; 29	1,025	478	?/1,000	1,750; 585	320/350	?	Limited-leakage
HWCTR	(?)	0	2	Circulation	4,800	140	1,500	545	?/60	1,800	?/250	75	Limited-leakage
Boiling-Water-Cooled Power Reactors													
EBWR	11/56	32	1§	Feed	180	1,700	−8	100	11/17	3,600	125/150	53	Limited-leakage
VBWR	3/60	4	2	Circulation	10,000	200	1,000	545	44/12–250	1,760	450/500	81	Limited-leakage
VSR	(?)	0	1 loop 2 pumps	Feed	290	3,000	20	140	?	?	?	?	Limited-leakage
Halden	6/58	12	1	Circulation	352	132	?	482	10/?	2,900	?/20	62	Canned-motor
Dresden	6/59	5	4	Circulation	17,500	100	1,005	543	45/105	1,184	410/536	66	Canned-motor
Kahl	6/60	0	1 loop 2 pumps	Feed	50	2,800	≤35	120	8/15	2,970	85/107	44	Limited-leakage
Sioux Falls	('62)	0	3	Circulation	20,000	71	600	486	24/54	585	325/400	79	Limited-leakage
Big Rock Pt.	(62)	0	2	?	16,000	76	1,510	580	?/25	900	?/400	?	Limited-leakage
Bonus	(10/61)	0	2	Circulation	4,500	60	950	532	25/30+	1,760	61/75	84	Limited-leakage
Japan BWR	(5/62)	0	1 loop 2 pumps	Feed	375	2,650	>25	≤135	25/>25	3,000	285/410	68	Limited-leakage
SENN	(62)	0	2	Circulation	26,000	115	1,005	530	45/varies	971	672/690	69	Canned-motor
AKV	(64)	0	1 loop 2 pumps§	Feed	?	?	?	?	?	?	?	?	Limited leakage
Spert-2	2/60	0.1	1 loop 2 pumps	Circulation	10,000	175	Varies	68–400	15/30	1,135	435–510/600	88	Limited-leakage
Spert-3	9/58	31	2 loops 4 pumps	Circulation	5,000	325	2,500	60–650	100/113	3,550	300/500	83	Canned-motor
Spert-4	Being	0	2	Circulation	2,500	220	5	≤130	7.5/11	1,775	125/125	78	Limited-leakage
Borax-5	8/60	0	1	Circulation	10,000	175	600	489	14/14.5	1,175	396/495	80	Limited-leakage
Aqueous Homogeneous Reactors													
HRE-1	1/52	15	1	Circulation	100	245	915	407	35/838	3,400	?/12	32	Canned-motor
HRE-2	10/56	20	1	Circulation	400	100	1,960	495	20/1,320	3,600	?/15	45	Canned-motor

* For more data on these and other reactors, see NU, Nov. '60, p. 148.
† Total dynamic head.

Power-Reactor Systems*

Seal				Materials			Weight, dry (~lb)	Size (~ft)		Cost (~$/ea.)	Manufacturer	Reactor
Type	Material	(gpm in)	(gpm out)	Impeller	Shaft	Casing		High	Diameter			
Can	Inconel	0	0	304ss	304ss	304ss	38,900	11.7	4	400,000	Westinghouse	Yankee
Can	Inconel	0	0	304ss	304ss	304ss	33,200	11.3	3.3	350,000	Westinghouse	Indian Point
Can	Inconel	0	0	304ss	304ss +Armco Fe	304ss	6,300	6.5	3.1	?	Allis-Chalmers	N.S. Savannah
Mechanical(2)	Stellite on carbon	0	3.6 gpd	5Cr-steel	Steel	5Cr-steel	20,000	13	3.7	56,000	Byron-Jackson	NPD
Mechanical	316ss stellited rotor, carbon stator	2	20	A-351	316ss	A-351	23,910	15.3	4.3	?	Byron-Jackson	CANDU
Can	?	0	0	18Cr 8NiCb	16Cr 2Ni	18Cr 8NiCb	10,000	7.2	2.8	?	Hayward-Tyler	R3/Adam
Can	Inconel	0	0	304ss	304ss	304ss	4,300	?	?	?	Westinghouse	SM-1
Can	Inconel	0	0	304ss	304ss	304ss	6,500	3.3	4, 6	?	Byron-Jackson	SM-1A
Can	Inconel	0	0	316ss	304ss	316ss	2,500	5.2	2.2	?	Byron-Jackson	PM-1
Can	Inconel	0	0	304ss	304ss	304ss	4,577	3	4, 6	?	Byron-Jackson	PM-2A
Can	Inconel	0	0	316ss	304ss	316ss	2,500	5.2	2.2	?	Byron-Jackson	PM-3A
Mechanical	A-336	70	0	A-351	316ss	?	25,000 (pump only)	7.2	7.2 × 6	150,000 (pump only)	Byron-Jackson	NPR
Mechanical	Stoody-Graphitar	0	0.1 gph	304ss	304ss	304ss	11,500	10.5	2.7	40,000	Byron-Jackson	PRTR
Mechanical	Tungsten carbide	<1	0	17-4PHss	17-4PHss	ss	4,650 (motor only)	10	4	50,000	Bingham	HWCTR
Labyrinth, rotary & mech.	Stellite and carbon ring	0	<5-6	12Cr stl	12-14Cr stl	4-6Cr stl	6,200	9.7	3.3	14,700	Allis-Chalmers	EBWR
Mechanical	Carbon-Durametal	4	1	304ss	17-4ss	304ss	6,000	12.7' long; $\frac{L}{R} = 2.43$		81,700 for both	Peerless Pump Co.	VBWR
?	?	?	?	?	?	?	?	6	12 × 4	15,000	?	VSR
Can	?	0	0	18-8ss	18-8ss	18-8ss	?	5.9	5.3	?	Hayward-Tyler	Halden
Can	Inconel	0	0	ss	ss	316ss	28,500	11.5	5, 5.5	?	General Electric	Dresden
Mechanical	?	?	?	13Cr 1.2Mo	13Cr	13Cr	3,560	10	2.1	?	Klein, Schanslin & Becker	Kahl
Floating bushing	Bronze bushings, ss shaft sleeve	6.3	0.7	304ss	304ss	304ss	42,400	13.5	5, 6.5	3 × std	Allis-Chalmers	Sioux Falls
Mechanical	?	?	Yes	SA-351	316ss	SA-351	80,500	12.5	7	?	Byron-Jackson	Big Rock Pt.
Mechanical(2)	Graphitar-Kennametal	<¼gph	<¼gph	304ss	316ss	304ss	3,500	6.5	3	24,000	Peerless	Bonus
Std stuffing box	?	0	Yes	Bronze	1Cr ½Mo	Cast steel	15,000	3.6	15.5, 3.6	?	Hitachi Ltd.	Japan BWR
Can	Inconel	0	0	A-351	304ss	A-351	34,210	12.9	2.5, 6.1	?	General Electric	SENN
?	?	?	?		Cr stl	ss	?	?	?	?	?	AKV
Mech (John Crane Type 9-B)	Cranamic-4, carbon	0	<180 cm³/hr	19Cr 9Ni	416ss	Ni-plated A-339	?	4.5	19 × 4.5	?	Allis-Chalmers	Spert-2
Can	304ss	0	0	304ss	410ss	304ss	8,500	7.3	2.7	89,500	Byron-Jackson	Spert-3
Stuffing box	Asbestos	?	?	304ss	SAE-4140	Cast Fe	1,800	3	3 × 7	3,870	Worthington	Spert-4
Mechanical	Graphite	1.5	1.5	304ss	304ss	304ss	18,000	12.5	5	80,000	Worthington	Borax-5
Can	347ss	1	0	347ss	Stellite-98M2	347ss	600	3	1.3	7,000	Westinghouse	HRE-1
Can	347ss	1	0	Ti → ss	347ss	347ss	1,100	2.9	1.5	29,000	Westinghouse	HRE-2

‡ Net positive suction head; design/available.
§ Plus 1 spare pump (CANDU has 2 spares); the SM-1A emergency pump has a mechanical seal.

VALVES

FOR WATER-COOLED POWER REACTORS

Valve problems in reactor systems have originated from causes typical in any power plant. But more reliable valves could reduce downtime, repairs and backup needs

by KENNETH H. GRUENWALD, *Allis-Chalmers Manufacturing Co., Milwaukee, Wisconsin*

SUCCESSFUL AND ECONOMICAL control and repair of reactor systems depend on valves that dependably regulate flow and pressure of the reactor coolant water without permitting large amounts of leakage. Reactor-system designers usually have given appropriate attention to nuclear requirements when selecting valves. Thus, valves generally have performed well, although there is room for improving the reliability of some of them. This could become difficult to do as reactor designers reach toward hotter, larger and lower-cost plants.

Nuclear Requirements

Nuclear valves must meet special standards in addition to the ones that other similar valves must meet. Once a system designer defines the function he wants a valve to perform, he must completely describe the fluid to be controlled so the valve designer or supplier can set the style, size, materials and construction details. For valves for conventional plants the system designer usually needs to specify only the fluid, pressure, temperature, flow rate, applicable code, type of driver and controller and the type of connection to the piping system. But nuclear-valve specifications are not complete until he also describes (a) permissible leakage across valve seat and through stem seal, (b) expected *p*H, conductivity, radioactivity level and type (gamma, beta, alpha or neutron), (c) future maintenance and inspection (direct or remote), (d) cleaning precautions, (e) alloys or alloying elements to be avoided (such as cobalt, mercury, lead, copper or zinc), (f) opening and closing times and (g) relationship between valve stroke and flow.

Radiation levels. Choice of materials for valves is affected by the radiation levels to which the valve components are exposed in the system. Most reactor-system steam or water lines normally are exposed to less than 100 r/hr. The main steam line of the Experimental Boiling Water Reactor (EBWR) is at only ~0.045 r/hr. But at full power the primary valves in aqueous-homogeneous-reactor systems are exposed to 100,000 r/hr by the fuel-coolant solution passing through them.

Conversely, to prevent the radioactivation of corrosion products that might be circulated through reactors with the coolant water, internal parts of valves and many other components of pressurized-water or boiling-water reactor systems usually are made of stainless steel, which resists corrosion better than carbon steel.

Leakage requirements. Two types of leakage are of concern. One involves water leakage across the seat within the valve body. For conventional service, designers consider "commercial tightness" to mean seat leakage of no more than 10 cm^3/hr/in. of pipe diameter. But for nuclear service "exceptional tightness" is required—which means seat leakage of no more than 2 cm^3/hr/in. Actually, seat leakage sometimes can be turned into an advantage. For instance, the 22-in.-diameter butterfly valves used to control flow in the recirculation loops of the Sioux Falls ("Pathfinder") reactor are expected to leak ~12 gpm across the closed seat. This bypass flow will keep the loops at uniform temperature, thus preventing (a) additional thermally induced pipe stresses and (b) an abrupt reactivity addition caused by starting a cold recirculation pump (while other loops are hot and running) that would deliver a cold slug of water to the reactor core.

Water also leaks around the drive stem that connects the valve internals to the driver outside. Unlike leakage across the seat, radioactive water that leaks around the stem escapes the piping system. If this stem leakage involves water that is so radioactive, hot or toxic that it could cause a health hazard unless costly protective steps are taken, zero-leakage valves can be used. For instance, leakage can be prevented by using a valve having a bellows around the stem. But as water pressure, temperature and valve sizes increase, bellows become less reliable, particularly for long-stroke valves that operate frequently. For this reason, conventional limited-leakage stem seals are found in most major valves of the newer and larger plants. (A new development in zero-leakage valves—harmonic drive—is now being tried in ~10 test loops. So far, operation has been favorable.)

Valve Experience

Operation of the Experimental Boiling Water Reactor, the Army SM-1 plant and the Shippingport station for several years shows that relief valves tend to leak more than other valves.

EBWR experience. Even after four years the outleakage of water from the turbine and major valves of EBWR is less than the 2 lb/day limit of the original specifications. This indicates the adequacy of the standard stem-seals—soft packing, leak-offs and hard bushings—for boiling-water reactors.

SM-1 experience. In its first two years of operation the SM-1 pressurized-water reactor at Fort Belvoir experienced only four scram shutdowns caused by valve abnormalities (*1*). These four shutdowns totaled 214 hr. A faulty check valve in a recirculation line caused 13 hr downtime, a leaking safety valve caused 125 hr, a leaking primary pressure-relief valve caused 9 hr and a failed coil in a trip valve in the primary-pump cooling line caused 67 hr downtime. Another 18 malfunctions associated with valves occurred but did not cause the reactor to scram: (a) feedwater control valve leaked; (b) primary-coolant blowdown valve stuck open; (c) back-pressure control valve was not operating properly; (d) air-ejector valve remained open; (e) motor on primary blowdown valve was faulty (replaced); (f) evaporator feed valve would not close; (g) trip valve on steam-generator superheater could not reset; (h) pilot pressure valve on turbine boiler feed pump did not open enough; (i) a trip control valve opened all the way; (j) boiler feed automatic control valve was cycling; (k) a level control valve leaked; (l) valve controller (service water system) did not operate properly; (m) pressure-reducing valve (on chlorinizer) had ruptured diaphragm; (n) air-ejector-valve controller was inoperative; (o) inlet steam valve needed repair; (p) main steam-pressure-regulator control was changed (reset assembly and pilot valve); (q) coil on steam-dump trip was replaced; (r) steam-pressure-control system valve leaked. Some of these could be considered as instrument failures. Although several special maintenance activities required careful scheduling of work to avoid overexposing personnel, the radiation levels in the plant after two years of operation were not high enough to hinder maintenance work seriously.

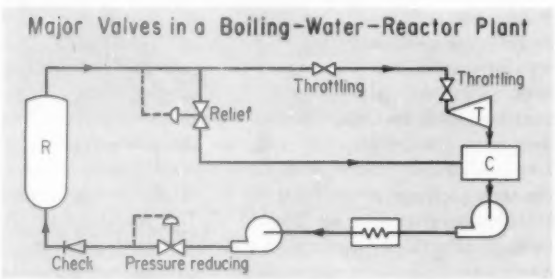
Shippingport Experience

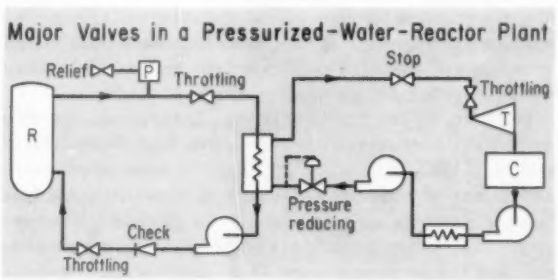
During the first two years of Shippingport operation coolant leakage from the reactor system ranged from 10 to 75 gal/hr, with the normal rate being ~35 gal/hr when the system was at operating pressure and temperature. Most of this leakage was through relief valves (2 on pressurizer, 4 on reactor, 4 on coolant loops and 8 on steam generators), vent valves and drain valves. Except for small leaks in some steam-generator tubes (the defective tubes have been plugged since), all this leakage is held within discharge lines inside the containment vessels surrounding the primary system. The plant designers intended to prevent coolant loss through vent and drain valves by installing exceptionally tight valves and keeping them firmly closed when not in use. But some leakage has occurred regardless of the quality of valves.

Relief-valve leakage. During initial plant operation at 2,000 psi both self-actuated steam-relief valves on the pressurizer leaked (as indicated by temperature measurements at the valves and on the discharge lines). When these valves were taken apart (without removing the bodies from the line) the nozzle seats and the disk seats were seen to be severely damaged by indentations, apparently caused by foreign particles; a small amount of wire-drawing had occurred where the indentations were closely spaced across the seat width. Leakage ceased after the operators lapped the nozzle seats and renewed the disks. But the valves began to leak slightly again after later plant tests in which a pressure surge approached the 2,300-psi set-point of these valves. This is significant—it indicates any test or actual operation of these valves will increase the chance of leakage. Later tests elsewhere with disk inserts ranging from the soft and ductile stainless steels to the very hard stellites confirmed this—with all inserts, significant leakage began when the pressure came within ~200 psi of the popping pressure. Seat damage does not seem to be the cause, disk thermal distortion or warpage might be.

These self-actuated relief valves continue to be the principal path for leakage from the reactor system. This leakage has not caused contamination problems (since the water always is contained in shielded piping or vessels), but it has required makeup water and processing by the radioactive-waste-disposal system. Even more important, the leaky pressurizer relief valves permit the escape of gases, principally hydrogen, that tend to collect in the pressurizer. During the past two years hydrogen loss has averaged 90–100 ft³/wk, with occasional peaks of ~150 ft³/wk. Since an excess of hydrogen must be held in the reactor coolant to retard corrosion of primary-system components, this leakage necessitates frequent hydrogen replenishment.

Alleviating leakage effects. When the Shippingport plant operating pressure was reduced from 2,000 psi to 1,800 psi in 1959 (to lessen chance of stress-corrosion failure of motor tubes on control-rod drive mechanisms atop reactor vessel), the operators did not change the 2,300-psi set-pressure of the pressurizer steam-relief valves. During 1,800-psi operation since then leak-





Valves for Water-Cooled Reactors—Their Types and Functions

At least 20 names are used to describe various types of valves, but functionally there are only four basic types:

1. **Throttling valves** control flow in either direction (typically, they also are called ball, gate, rotating-plug, -cone, globe, balanced, butterfly, diaphragm or needle valves, depending on their operating principles).

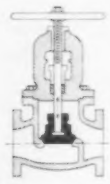
2. **Check valves** prevent flow in the reverse direction (also called non-return or stop-check valves).

3. **Pressure-reducing valves** control downstream pressure (also called regulating or isolation valves).

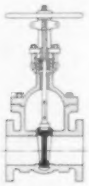
4. **Relief valves** establish or limit upstream pressure (also called back-pressure, safety, dump, pop or burst valves).

Which Valve Types Are Suitable for Various Reactor Services?

	Location and function							
	Primary-water loops		*Main steam lines*		*Feedwater*			
Valve type	*Control*	*Isolation*	*Control*	*Isolation*	*Control*	*Isolation*	*Steam dump or bypass*	*Water purification cycles*
Globe	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Gate	No	Yes	No	Yes	No	Yes	No	No
Butterfly (rubber seat)	No	No	No	No	No	?	No	Yes
Butterfly (metal seat)	Yes	Yes	No	No	No	?	No	Yes
Rotating plug	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ball	Yes	Yes	?	Yes	Yes	Yes	?	Yes
Diaphragm	No	No	No	No	?	?	No	Yes

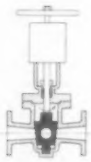


Globe Valve

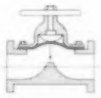


Gate Valve

Butterfly Valve



Rotating-Plug Valve



Diaphragm Valve

Globe valves are relatively inexpensive in sizes up to 6 in. But larger sizes become more expensive compared to other valves. They are excellent for throttling service because the disk can be in intermediate positions as well as wide open or fully closed. They can shut off tightly, but unless they are oversize, globe valves even when they are wide open usually resist fluid flow to some extent. If flow varies widely a single valve wears abnormally, so a pair often is used, which also permits finer flow regulation.

Gate valves are comparatively inexpensive in sizes under 36 in. But above 20–24 in. a bypass valve often is needed to equalize pressure across a gate valve so less force is required to open it. Best suited for service fully open or closed, gate valves are not recommended for throttling conditions or for rapid opening and closing. Open gate valves offer little resistance to flow, so they are used most often for isolating components in piping systems. Leaktight shutoff is not a problem for gate valves operating with clean low-temperature water. But with water hotter than 400° F and with frequent operating cycles wear and distortion of seating surfaces cause more leakage.

Butterfly valves are simple, having only one moving assembly. This means low initial cost, high dependability and little maintenance. They adapt to most installations and means of operation. Because they are compact and light no supports are needed except for pipeline. They are excellent for either throttling or on-off service over wide pressure and temperature ranges. Like gate valves, they offer little resistance to flow when open. They operate with one-quarter (or less) revolution of shaft from full-open to full close; low surface friction permits small actuators. Metal-to-metal seating keeps leakage across the seat low, but if drop-tight or bubble-tight closure is important, rubber seats can be used at 180° F or less.

Rotating-plug or -cone valves are used where higher pressures, temperatures and more stringent leakage requirements eliminate butterfly valves. Although more expensive than butterfly valves, plug valves have the advantages of compactness, long service life, ready adaptability to any type of operator or automatic controller and lowest head loss when wide open (no more resistance to flow than a straight piece of pipe—which means low pumping cost). They can be used for throttling service, but are applied more often to open-shut operation.

Diaphragm valves have three simple elements: body, diaphragm and bonnet assembly. The diaphragm serves as the closing member (or seat) as well as partition that separates valve working parts (bonnet) from fluid passageway. They are drip-tight, bubble-tight and have no conventional stem packing. They are widely used for throttling service in low-temperature water or chemical-process systems (such as water-purification cycles having ion-exchangers). Sizes range from ½ to 16 in.; pressures and temperatures usually are limited to 150 psi and 220° F. Occasionally this type of valve is confused with one using a diaphragm in the actuator, such as an air-motor diaphragm.

age from the reactor system has dropped to an average of 10 gal/hr.

Since all reactor-vessel and pressurizer relief valves discharge to a common header leading to a blowoff tank in which the effluent is cooled and condensed before transfer to the waste-disposal system, the plant operators could not determine which valve was leaking (without tedious temperature measurements) or measure leak rates individually. Now that a system has been installed to measure leakage from individual relief valves, the operator can tell when valve repair is needed and by which valve.

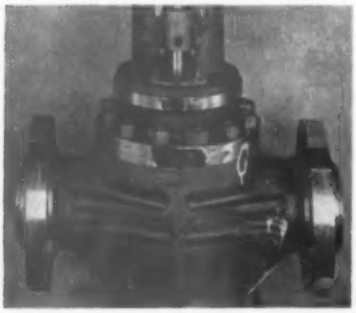
To stop hydrogen loss through the two leaky relief valves in the pressurizer, the discharge piping has been changed to form a water seal just upstream of the steam-relief valves.

Although self-actuated main safety valves are leaktight when installed, the seats often start to leak after several opening-closing cycles. Perhaps the problem could be solved as it has been in some advanced conventional high-pressure plants (such as the Breed Plant of the Indiana and Michigan Electric Co.), by installing a relief valve with an actuator that opens the valve at a pressure below the set point of the standard code safety valves (after the pressure is relieved, the actuator closes the valve tightly). Since the normal self-actuated safety valves probably never will be called on to operate, they should maintain their original leaktightness.

Other valve troubles. Lesser valve problems also arose during Shippingport's first two years. A butterfly valve on a circulating pump failed to open when the cast-iron quadrant gear connecting the valve to its drive cylinder broke. Water vapor released during tests of a solenoid-actuated steam-relief valve shorted the solenoid coils so that the valve failed to close properly; to prevent a recurrence, the solenoids have been relocated in a drier area. During tests of the relief valves the reactor relief valve opened at the same time as the pressurizer relief valve and failed to reseat, which nearly drained the pressurizer completely; the operators gagged the valve manually until they could adjust the set point.

With the valve-position detectors located in the reactor area, heat and radiation caused their terminal block and wiring to oxidize, which raised the resistance in the secondary coils of the differential transformers. The system temperature gradient affected the voltages from the detectors enough that the bias settings of the indicator receivers had to be adjusted frequently.

Only once has component failure caused radioactive water to leak into the atmosphere of the containment vessel. That was when a crack opened in a seal weld between the body and cap of a valve in one of the water-purification loops. When a rising radiation level in the purification cubicle indicated the leak had occurred, the operators quickly isolated the loop, found the trouble and made repairs while plant operations continued with another purification loop in a second cubicle.



FLANGES on nozzles of 6-in. 900-psi rotating-plug valve serve as heat sinks when valve is butt-welded into piping system, thus reducing distortion that often causes across-seat leakage. Flanges also ease fabrication and shop testing, thus lowering the cost of such valves

Nuclear Valve Trends

Both operating experience and reactor-design advances point toward valves that are cheaper and more efficient.

Specifications. Early specifications for nuclear valves often specified zero leakage and special materials. But radiation hazards caused by leakage from water-cooled-reactor systems generally have proven to be less than had been expected. So designers now tend to realize that it costs less to design the plant to accomodate some leakage than to try to eliminate it entirely.

Backup valves. For safety reasons both conventional power plants and nuclear plants often use a second set of independently operated valves to control or isolate key systems. This is particularly the case for the quick-closing isolation valves in the piping of the reactor system and in containment-vessel ventilation ducts. But these backup valves double the number of valves used in some systems. As plant operation demonstrates valve reliability, some of these duplications can be eliminated.

Larger plants = larger valves. Since larger power plants (both conventional and nuclear) are being built to improve efficiency and reduce capital costs, larger valves are needed also. But as valves get larger it becomes harder to restrict leakage. Thus, for nuclear service it might become advisable to install two small valves rather than one large valve. Duplex units with two valves within one body probably will play increasingly prevalent roles in future nuclear plants.

Hotter plants. To improve cycle efficiency reactor designers are moving toward higher temperatures and pressures. The introduction of nuclear superheat in the Sioux Falls, Bonus and Vallecitos Superheat Reactor plants (and the future possibilities of nuclear reheat) foretell the need for valves to operate with 2,400-psi 1,050° F steam. Whether these nuclear valves must and can meet today's stringent material and leakage requirements remains to be seen.

Automatic control. To permit plant control by computers we must obtain more accurate data on valve closing times, flow versus stroke characteristics and stem and seat leakage rates. We need these data even today so we can better analyze reactor control during power transients and can compute the consequences of radioactivity release more accurately.

Valve alternatives. Although valves now are the basic tools for controlling reactor-coolant flow, some reactor-system designers have an eye focused on methods of flow control that might replace some valves—in the future variable-speed pumps might be used more widely and electrical fields or sound waves might control flow.

BIBLIOGRAPHY

1. R. E. May, O. N. Childs, J. H. Morrison. Instrumentation and controls study for SM-1 nuclear power plant. APAE-52, vol. 1 (1959)
2. J. E. Gray, W. H. Hamilton, W. E. Wynne. Shippingport operations from startup to first refueling, December 1957 to October 1959, report no. 364 (Duquesne Light Co., 1960)
3. J. P. Thorel. Leakproof valves for water-cooled reactors, NUCLEONICS **14,** No. 10, 96 (1956)
4. Valve types and applications, *Nuclear Power* **5,** No. 53, 93 (1960)

Main Check, Stop and Relief Power-Reactor

Reactor	Valve function	Valve location	No. per loop	No. of loops	Install-ation date	Seat diameter (~in.)	Operating conditions: Temp. (°F)	Pressure (psi)	Flow (gpm water or lb/hr stm.)	Action
Pressurized-Water-Cooled Power Reactors										
Yankee	Check	Pump discharge	1	4	12/59	16.22	496	2,000	23,700 gpm	Swinging disk
	Stop	Pump discharge; stm. gen. inlet	2	4	12/59	14.50	532-	2,000	23,700 gpm	Sliding disk
	Relief	Pressurizer	2	4	6/60	1.00	636	2,400	92,000 lb/hr	Spring-loaded disk
	Solenoid relief	Pressurizer	1	4	5/60	1.00	636	2,400	50,000 lb/hr	Balancing piston
Indian Point	Check	Discharge of each pump	2	4	?	14	510	1,485	16,000 gpm	Swing check
	Stop	Reactor inlet and outlet	2	4	?	19.625	510	1,485	32,000 gpm	Sliding gate
	Relief	At pump discharge	1	4	?	0.375	480	1,485	30 gpm	Spring loaded
	Relief	On pressurizer	4 total		?	1.0	596	1,485	45,000 lb/hr	Spring loaded
N.S. Savannah	Check	At pump discharge	2	2	?	9.0	495	1,735	5,000 gpm	Tilting disk swing
	Stop	Reactor inlet and outlet	2	2	?	11.37	520	1,735	10,000 gpm	Split-wedge disk
	Relief	On pressurizer	2 total		?	0.62	650-	2,000	18,358 lb/hr	Spring loaded
NPD	Check	At pump discharge	3	1	2/61	9.5	485	1,125	6,000 gpm	Swing check
	Stop*	1 on pump exit; 1 on HX inlet	2*	1	2/61	9	485–530	1,125	12,000 gpm	Parallel slide
	Relief	On pressurizer	1 only		2/61	?	555	1,108	500 lb/hr	Lift
CANDU	Stop†	On boilers	16†	1	?	7.0	560	1,350	7,500 gpm	Parallel sliding disks
NPR	Check	Pump discharge	1	5	(1962)	21.25	600	1,825	32,000 gpm	?
	Stop‡	Cell inlet and outlet	‡	5	(1962)	21.25	600	1,825	32,000 gpm	?
	Relief	Primary loop	1	5	(1962)	?	600	1,825	600 gpm	?
PRTR	Check	Pump outlet	3	1	1960	?	478	1,110	4,200 gpm	Swing check
	Check	Pump bypass	1	1	1960	8	478	1,110	200 gpm	Air-actuator (open) swing
	Stop	Before heat exchanger	1	1	1960	12	530	1,025	8,900 gpm	Sliding disk
	Stop	Pump inlet	3	1	1960	9	478	1,005	4,200 gpm	Sliding gate
	Stop	Reactor tube inlet	85	1	1960	1.5	478	1,110	123 gpm	Air or backflow
	Relief	Atop pressurizer	2 only		1960	2	478	1,025	4 ft³/sec	Sliding plug
HWCTR	Stop	Reactor inlet and outlet	2	2	3/61	8.7	428–545	1,000–1,500	5,000 gpm	Sliding disk
	Relief	Purge line to purifier	2 only		3/61	1.5	86	1,000–1,500	150 gpm	Lift
Boiling-Water-Cooled Power Reactors										
EBWR	Check	Feedwater	3	1	1956	3" inlet	120	900	120 gpm	Lift and swing
	Stop	Steam and feedwater	11	1	1956	3", 4", 6" inlet	489; 120	600; 900	120 gpm	Gate and plug
	Relief	Steam	4	1	1956	3", 4", 6" inlet	489	600	64,000 lb/hr	Plug
VBWR	Stop	Ahead of pumps	1	2	1957	16" inlet	545	1,000	10,000 gpm	Manual
VSR	Check	At enclosure	3	1	(1962)	6", 8" nom.	550	1,000	150,000 lb/hr	?
	Stop	At enclosure (valve pit)	6	1	(1962)	6", 8" nom.	550; 1,100	1,000	150,000 lb/hr	?
	Relief	Reactor vessel (2); fuel pool (2)	4	1	(1962)	3", 6" nom.	550; 1,100	1,000	150,000 lb/hr	?
Halden	Stop	D_2O steam	2	2	1958	6.9	482	588	11 ft³/sec	Sliding disk
Kahl	Check	Pump discharge & reactor inlet	3	1	1960	2	150	1,250	60 gpm	Seated
	Stop	Throughout loop	4	1	1960	2; 1	572	1,250	60 gpm	Sliding disk; double port
	Relief	After heat exchanger	2	1	1960	1	150	1,250	60 gpm	?
Elk River	Stop	Steam to evaporator	2	2	11/60	8" nom.	?	?	?	Sliding disk
	Stop	Condensate to reactor	1	2	11/60	6" nom.	?	?	?	Sliding disk
Sioux Falls	Stop	Steam line	1	3	(1962)	12	825	545	615,000 lb/hr	Rotating plug
	Relief	Steam line	4	3	(1962)	3.25	825	593–610	180,000 lb/hr	Spring, balanced bellows
Humboldt Bay	Relief	Vessel head	4	1	(1962)	4" inlet	570	1,250	409,000 lb/hr	?
Big Rock Pt.	Stop	Pump inlet and outlet	2	2	(?)	16; 18	?	1,500–	16,000 gpm	?
Bonus	Stop	Superheated-steam line	1	2	(Late '61)	8" inlet	900	950–	152,000 lb/hr	Sliding disk gate
	Stop	Pump-loop inlet and outlet	2	2	(Late '61)	10," 12" inlets	532–543	950	4,500 gpm	Single-wedge disk
	Check	Pump discharge	1	2	(Late '61)	10" inlet	532–543	950	4,500 gpm	Swing check
	Relief	Sat.-steam manifold on reactor vessel	3 total		(Late '61)	6" inlet	543	950	60,000 lb/hr	?
SENN	Stop	Between secondary stm. gen. and reactor	1	2	10/61	19.62 port	530	1,025	9,155,000 lb/hr	Sliding disk
	Relief	On primary steam drum	6 total		12/61	3	545	1,000	?	Pop type
Spert-2	Check	Pump discharge	2	1	2/60	16	400–	375	10,000– gpm	Tilting angle disk
Spert-3	Check	Pump discharge	2	2	9/58	10	650	2,500	5,000 gpm	Swing check
	Blowdown	Reactor outlet	1 only		9/58	0.5	650	2,500	?	Needle
	Blowoff	Pressurizer	1 only		9/58	1.25	650	2,500 stm.	?	Needle
Spert-4	Check	Pump discharge	2	1	4/61	10.4	135	80	5,000 gpm	Swinging disk
	Stop	Pump inlet and outlet	2;6;1	1	4/61	11.5; 13.5; 16.0	135	80	5,000 gpm	Sliding wedge gate
Borax-5	Stop	Pump suction	1	1	1/61	16	489	600	10,000 gpm	Sliding disk
	Stop	Primary steam line	1	1	1/61	6	489–850	600	100,000 lb/hr	Sliding disk
	Relief	Primary steam line	4	1	1/61	?	489–850	388–670	60,000 lb/hr	Pop-off
Aqueous Homogeneous Power Reactors										
HRE-1	Stop	Various locations	~30 total		50–52	0.625	482	1,000	Varied	60-deg conical plug
HRE-2	Stop	Various locations	~16 total		1956	0.125	572	1,800	1.5 gpm	60-deg conical plug
	Stop	Various locations	~35 total		1956	0.625	300–	500–	Varied	60-deg conical plug

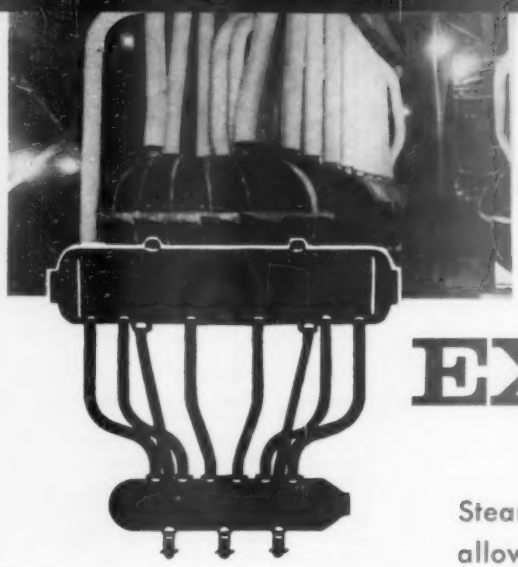
* These NPD stop valves are motor-driven; in addition there is a duplicate valve (but manually driven) on the pump suction; it costs $3,800 each. † There also will be 10 check valves on the CANDU pumps; design details and supplier have not been

Valves in Water-Cooled Systems

Materials				Cost		Weight	Valve	
Body	Plug	Seat	Stem seal	(~$/ea.)	Manufacturer	(~lb/ea.)	function	Reactor
304ss	410ss	?	?	24,190	Westinghouse	4,280	Check	Yankee
304ss	Stellite-6	Stellite-6	Graphitized asbestos formed rings	39,460	Westinghouse	7,000	Stop	
304ss	?	?	1.625" Allegheny AM-350 bellows	5,200	Man.-Max.-Moore	?	Relief	
304ss	Stellite-6	Stellite-6	?	6,400	Man.-Max.-Moore	?	Solenoid relief	
A351	316ss	Stellite-6	—	?	Edward	5,070	Check	Indian Point
304ss	347ss	304ss	Graphitized asbestos stuffing	60,000	Crane	31,000	Stop	
304ss	Haynes-25	304ss	316ss bellows	1,380	Crosby	35	Relief	
304ss	Haynes-25	304ss	316ss bellows	3,750	Crosby	150	Relief	
316ss	316ss-Stellite-6	316ss-Stellite-6	—	?	Edward	1,010	Check	N.S. Savannah
304ss	347ss-Stellite-6	Stellite-6	304ss square stuffing	?	Crane	6,500	Stop	
C steel	Inconel-X	304ss	0.62" 316ss bellows	?	Man.-Max.-Moore	?	Relief	
C steel	304ss	304ss	—	4,167	Darling	925	Check	NPD
C steel	Hopkinson Platnam	Hopkinson	Graphitized asbestos, leakoff	4,054	Hopkinson-Ferranti	3,136	Stop	
C steel	Stellite	Stellite	—	500	?	?	Relief	
A-216WCB	A217	?	2 Metaflex asbestos, leakoff	?	Hopkinson	2,520	Stop	CANDU
C steel	304ss	Stellite	Double stuffing boxes with two sets	15,000	Atwood & Morrill	6,700	Check	NPR
C steel	304ss	Stellite	of packing (6" rings/set) and leak-	40,000	Anchor	15,560	Stop	
C steel	?	Stellite	off between	6,000	Not selected	?	Relief	
304ss	304ss-Stellite	316ss-Stellite	—	5,100	Schutte-Koerting	?	Check	PRTR
304ss	Stellite	Stellite	—	5,900	Atwood & Morrill	?	Check	
316ss	316ss-Stellite	Stellite	Lantern ring stuffing, plus white as-	19,800	Wm. Powell	?	Stop	
316ss	316ss-Stellite	Stellite	bestos, teflon-asbestos	?	Wm. Powell	?	Stop	
316ss	316ss-Stellite	Stellite	Same, but no plain white asbestos	300	Alloyco	?	Stop	
304ss	304ss	304ss	—	850	Man.-Max.-Moore	?	Relief	
A216WCB	—	A285C	Teflon cup and cone	6,726	Chapman	4,350	Stop	HWCTR
A216WCB	—	304ss	316ss(ELC) bellows	496	Consolidated	85	Relief	
304ss	Stellited	Stellited	—	?	Crane	?	Check	EBWR
C steel & 304ss	Stellited	Stellited	Asbestos square stuffing	?	Crane; Powell; Cooper Alloy	?	Stop	
C steel	Stellited	Stellited	—	?	Consolidated, Foster Gimpel	?	Relief	
304ss	Stellite	Stellite	Teflon-asbestos rings	15,000	Crane	8,750	Stop	VBWR
?	?	?	?	?	?	?	Check	VSR
?	?	?	?	?	?	?	Stop	
?	?	?	?	?	?	?	Relief	
ss	?	Stellite	Stainless-steel bellows	2,000	Dikkers	?	Stop	Halden
347ss	ss	Stellite	—	?	Amag-Hilpert	?	Check	Kahl
347ss	316ss	316ss-Stellite	Metallized asbestos, teflon rings, leakoff	?	Honeywell; Amag-Hilpert	?	Stop	
Cast steel	ss	ss	—	?	Babcock Werke	?	Relief	
316ss	316ss	Stellite	Teflon asbestos C-95	4,300	Crane	865	Stop	Elk River
316ss	316ss	Stellite	Teflon asbestos C-95	2,900	Crane	900	Stop	
A217WC6	A217WC6	Stellite-6	Asbestos rings (5) with Inconel wire	18,500	Allis-Chalmers	5,000	Stop	Sioux Falls
A217WC9	304ss	304ss	AM-355ss bellows	2,000	Crosby	?	Relief	
Manning, Maxwell & Moore Catalog No. 1767A				?	←	?	Relief	Humboldt Bay
A351CF8M	CV-21 faced	CV-21 faced	Stuffing box	?	Chapman	?	Stop	Big Rock Pt.
?	?	?	?	?	Not selected yet	?	Stop	Bonus
?	304ss	Stellite	Leak-off seal	?	?	?	Stop	
?	304ss	Stellite	?	?	?	?	Check	
?	?	?	?	?	?	?	Relief	
316ss	316ss	Stellite	Graphitized-asbestos rings	?	Dikkers	?	Stop	SENN
A216WCB	304ss	304ss	Totally enclosed	?	Crosby	?	Relief	
304Lss	304Lss	304Lss	?	?	Fabri-Valve	?	Check	Spert-2
304ss	304ss	Stellite	?	?	Cooper Alloy	?	Check	Spert-3
316ss	316ss	Stellite face	Dura-Metallic chevrons	?	Fisher Governor	?	Blowdown	
316ss	316ss	Stellite face	Dura-Metallic chevrons	?	Fisher Governor	?	Blowoff	
T304ss	T304ss	T304ss	?	?	R. V. Rovang & Associates	300	Check	Spert-4
T304ss	T304ss	T304ss	Asbestos-teflon chevrons	?	R. V. Rovang & Associates	350; 500; 600	Stop	
304ss	Stellite	Stellite	?	?	Chapman	4,000	Stop	Borax-5
1.5Cr0.5Mo	11-13Cr-ss	11-13Cr-ss	Graphitized asbestos rings	?	Anchor Equipment	1,000	Stop	
Alloy steel	Monel	Monel	3" ss bellows	?	Crosby	400	Relief	
347ss	Stellite-6	Stellite-12	347ss 1.125" bellows	450	Robertshaw-Fulton	40	Stop	HRE-1
347ss	347ss	347ss	347ss 1.125" bellows	1,125	Robertshaw-Fulton	80	Stop	HRE-2
347ss	Stellite-6	Stellite-12	347ss 1.125" bellows	875	Robertshaw-Fulton	80	Stop	

selected yet. ‡ Each NPR loop has one 24-in., two 18-in. and one 26-in. gate-type stop valves; data in table are for 24-in. valve.

Throttling valves are not included in this compilation. For more data on these and other reactors see NU, Nov. '60, p. 148.



HEAT EXCHANGERS

FOR WATER-COOLED POWER REACTORS

Steam-generator costs will fall as operating experience allows designers to relax rigid specifications and gain confidence in cheaper materials and new configurations

by GEORGE T. LEWIS, Jr., MICHAEL ZIZZA and PAUL P. DE RIENZO
Burns and Roe, Inc., Hempstead, New York

PER SQUARE FOOT of heat-transfer surface, nuclear steam generators cost roughly five times as much as the conventional liquid-to-liquid reboilers and evaporators found in chemical processing plants.

Part of this difference is justified by the inherently more difficult job that nuclear heat exchangers have to perform. Whereas the conventional reboiler works at maximum pressures of 200–300 psi with very little pressure difference between tube side and shell side, the tube-side pressure in a steam generator for a water-cooled power reactor may have an absolute value of 2,000 psi with the secondary-side pressure only one third to one tenth of this. The nuclear system must be able to withstand the very rapid thermal cycles characteristic of power-reactor operation in which temperatures change in a matter of minutes rather than in hours as in a conventional plant. Finally nuclear heat exchangers must be designed to guarantee containment of the radioactive primary coolant.

These added requirements have led designers to go beyond the established practice for reboilers and evaporators and do such things as substitute stainless for carbon steel, weld tubes into tube sheets (instead of merely rolling them in) and assemble heat-exchanger components under exacting conditions of cleanliness. Although nuclear heat exchangers built with these expensive innovations perform quite well, no one doubts that they are overdesigned in many ways. Many more years of operating experience will be needed, however, before we can finally decide which aspects of present-day design are excessively conservative.

Even so, the limited experience to date has given rise to some new trends in thinking about how to reduce steam-generator costs. We will first review current design practice and then discuss the areas in which we can begin to foresee these changes coming about.

Because of space limitations, we will discuss only main heat exchangers or steam generators, and only for pressurized-water and dual-cycle boiling-water power reactors.

In dual-cycle boiling plants (the Dresden plant, for example) we refer to the external steam generators that produce additional lower-pressure steam by absorbing heat from the condensate collected in the primary steam drum. These secondary generators are equivalent to the steam generators in the pressurized-water-reactor cycle.

PERFORMANCE

Although there are many possible configurations (see box) for the steam generators installed in pressurized-water or dual-cycle boiling-water nuclear power reactors, the design considerations from a performance standpoint are substantially the same for each configuration. In general, it is difficult to differentiate between design features that affect only performance or only reliability since a steam generator that performs satisfactorily in a thermal sense must at the same time be reliable in this performance. Therefore, besides thermal design and steam separation efficiency, we have included under performance the topics of flow distribution and transient behavior.

Heat-Transfer Rate

A wealth of published data (*2–6*) serves as the basis for the thermal design of heat exchangers. For preliminary estimating purposes, we can use the following expression to determine the required heat-transfer surface area.

$$A_o = \frac{q}{U_o \Delta T_{lm}} \qquad (1)$$

To a first approximation q and ΔT_{lm} (see box on p. 78 for definitions) are determined by the reactor thermal rating and coolant temperatures (plus the saturated-steam temperature for ΔT_{lm}). Hence the required area A_o depends primarily on what value of U_o can be obtained. Although wide variations in U_o, the over-all coefficient of heat transfer, are possible through variations in steam-generator design or operating conditions, the normal range of values for U_o is between 600 and 900 Btu/hr-ft²-°F.

A more accurate procedure that takes into account the primary-coolant film coefficient, the tube wall and foul-

ing resistances and the boiling-film coefficient (including the effect of tube wall temperature) makes use of an integrated equation of the form

$$A_o = m_p c_{p_p} \left\{ \frac{3}{h_{i_1} w_{1s}} \ln \frac{\Delta T_{o_2}}{\Delta T_{o_1}} + \frac{1}{2K} \left[\frac{1}{(\Delta T_{o_2})^2} - \frac{1}{(\Delta T_{o_1})} \right] \right\} \quad (2)$$

where K is the boiling coefficient constant in the Rohsenow (7) correlation, the subscript 1 refers to the steam-generator inlet and 2 to the exit, and $\Delta T_o = T_w - T_b$ is the temperature difference due to the boiling coefficient. The term $h_{i_1} w_{1s}$ in Eqs. 2 and 3 includes all factors but the boiling film coefficient and is defined as

$$h_{i_1} w_{1s} = \left[\frac{1}{h_i} \frac{A_o}{A_i} + f_{s_i} \frac{A_o}{A_i} + \frac{(r_o - r_i)}{k_w} \frac{A_o}{A_m} + f_{s_o} \right]^{-1} \quad (3)$$

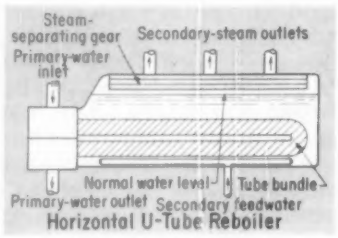
The following conditions hold at the steam-generator ends

$$(\Delta T_{tot})_1 = \left[\frac{K}{h_{i_1} w_{1s}} (\Delta T_{o_1})^2 + 1 \right] \Delta T_{o_1}$$

and

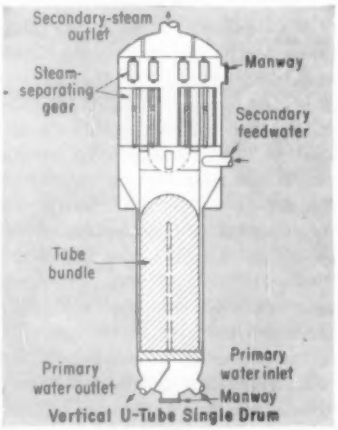
$$(\Delta T_{tot})_2 = \left[\frac{K}{h_{i_1} w_{1s}} (\Delta T_{o_2})^2 + 1 \right] \Delta T_{o_2} \quad (4)$$

Equations 2 and 4 will determine the surface-area requirements of a steam



Horizontal U-Tube Reboiler

A



Vertical U-Tube Single Drum

B

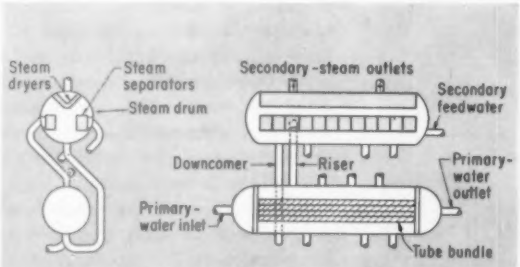
Nuclear Steam Generators—Basic Types

One can classify nuclear steam generators according to three basic characteristics:

- Generator orientation—horizontal or vertical
- Tube-bundle configuration—straight or U tube
- Steam separation—single-drum or reboiler type (steam separation takes place in the same drum that contains the tube bundle) or multiple-drum type (steam separation occurs in a drum or drums separate from and connected by risers and downcomers to the drum containing the tube bundle). A steam generator design can incorporate any combination of the three basic design categories with many variations possible in a given category. Hence the engineer has substantial latitude in selecting a steam-generator design. Figures A, B and C show three of the possible arrangements.

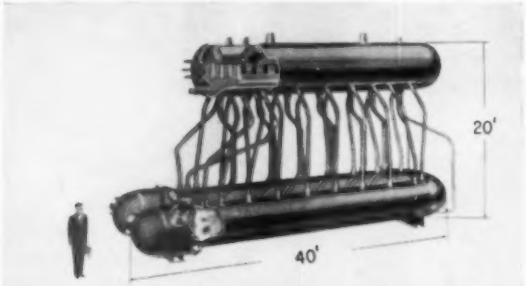
The two categories of tube bundle configuration have several significant variations. An exchanger can have a straight tube with both tubesheets fixed (1). In this arrangement differential expansion between the tubes and the shell is compensated by an expansion joint in the shell or by bowing or bending of the tubes. A straight-tube-bundle exchanger can also have one fixed tubesheet and one movable tubesheet mounted integral with a floating head. In this arrangement, the movable tubesheet eliminates the need for expansion joints or a flexible tube bundle. U-shaped tubes with either a straight-shell or contour-shell arrangement also are a solution to the problem of differential expansion between the tubes and the shell. For a U tube bundle in a straight shell, the head or channel assembly has one or more divider plates to separate the inlet and outlet ends of the individual U tubes for each pass. A significant variation of this design is a U-shaped shell assembly with separate tube sheets at each end connected by tubes that conform to the contour of the shell (Fig. D). Clearances between the tube bundle and the shell wall are large enough to take care of the differential expansion.

C



Horizontal Straight-Tube Multiple Drum

D



Horizontal U-Tube with Contour Shell and Multiple Drum

generator when solved by trial and error.

To minimize the amount of boiling-side heat-transfer surface area required one tries to make the film coefficient h_i as large as possible and the fouling factors f_{si} and f_{so} and the wall conduction term $(r_o - r_i)/k_w$ as small as possible.

Primary-side coefficient. The heat-transfer coefficient of the primary fluid, h_i, depends on mass velocity, viscosity, thermal conductivity, specific heat and the tube diameter. For a relatively nonviscous fluid, such as water, and for turbulent flow (i.e., Reynolds number > 3,100) inside tubes, an accepted correlation is

$$h_i = \frac{k_m}{D}\left[0.023\left(\frac{DG_t}{\mu_m}\right)^{0.8}\left(\frac{c_p\mu}{k}\right)_m^{0.33}\right] \quad (5)$$

The upper limit for h_i depends on how large a G_t can be tolerated from the viewpoints of pressure drop and erosion. For stainless-steel tubes, tubeside velocities of about 15–20 ft/sec are permissible from the erosion standpoint, however, pumping costs usually limit tubeside velocity to 10–15 ft/sec. This corresponds to mass velocities of 600–900 lbm/sec-ft².

Secondary-side coefficient. On the shell side, boiling is restricted to the nucleate region and a maximum boiling film coefficient of 3,000 Btu/hr-ft²-°F for steam is a typical value adopted for preliminary estimates.

The methods used to predict nucleate boiling coefficients rely on correlations that are partly theoretical and partly empirical (*7, 9*). The approach formulated by Rohsenow (*7*) assumes that heat flows from the hot surface to the liquid and from the liquid to the vapor bubbles. The heat-transfer resistance is considered to be a stagnant film around the bubbles. Rohsenow's analysis takes the view that the movement of fully formed bubbles at the instant of breaking away from the surface is of prime importance and that during nucleate boiling, heat flows from the hot solid surface into the superheated sublayer and then into the vapor bubble. A boiling film coefficient correlation developed from Rohsenow's work is expressed as

$$h_o = K(T_w - T_b)^2 \quad (6)$$

where T_b is the temperature of the bulk saturated water on the secondary side of the steam generator (for design purposes this is assumed to be equal to T_s, the saturated steam temperature), and K may be related to the steam temperature by

$$K = 2.805 \times 10^{-11} T_s^{4.73} \quad (7)$$

Fouling factors. The scale or fouling resistance terms, f_{si} and f_{so} in Eq. 3 represent safety factors that increase the design surface of the heat exchanger to compensate for scale buildup on tube surfaces between cleaning cycles. For primary water, a high purity is generally maintained through either a bypass demineralization system or by a makeup and bleed system. Therefore, the fouling term f_{si} on the primary side can be neglected.

Although the purity of the secondary water is also closely maintained, for economic purposes the requirements are usually not as stringent as those for the primary side. For this reason, a certain amount of fouling will occur on the secondary side. An allowance of 0.0003°F-ft²-hr/Btu is generally accepted as reasonable for the secondary-side fouling factor.

Wall resistance. The term $(r_i - r_o)/k_w$ depends on the thermal conductivity of the tube material and the wall thickness. For a given material the wall-resistance term is reduced to a minimum by making the tube wall as thin as pressure and attack from erosion and corrosion will allow.

Combined resistance. The following table illustrates the relative influence of the various resistances to heat transfer:

Equivalent Thermal Resistance

	(°F-ft²-hr/Btu)	(% of total)
Inside-film resistance (corrected)	0.000192	15.9
Tube-wall resistance	0.000435	35.9
Secondary-side fouling factor	0.0003	24.8
Boiling-film resistance	0.000282	23.4
Total	0.001209	100.0

The values of resistance have been weighted on a percentage basis for a typical nuclear steam generator with ⅝-in. o.d. stainless-steel tubes with 0.049-in. wall thickness, a 12.5-ft/sec tubeside velocity, 500-psia secondary side steam and a secondary side fouling factor of 0.0003°F-ft²-hr/Btu.

DNB heat-flux limit. Although the average heat flux is far below the limit imposed by the DNB point, the designer must check to be sure that the heat flux does not exceed this limit in local regions. The most likely region is the primary coolant inlet, where the temperature difference between the primary and secondary side is largest. There he compares expected heat flux (based on area predicted by the methods presented in the previous sections) with the predicted DNB heat flux. The latter, especially can not be calculated with great accuracy. Hence designers typically keep the maximum local heat flux at one half to one third the predicted DNB flux.

The factors important in establishing the DNB flux are bubble population, the rate of bubble formation and the dynamics of each bubble. The last factors are functions of the liquid superheat temperature $(T_w - T_b)$. Rohsenow and Griffith (*7*) and Forster and Zuber (*8*) have empirical relationships that can be used to predict the DNB flux. Both correlations have experimental substantiation.

Moisture Separation

Still another measure of steam-generator performance is the level of moisture content in the saturated steam supplied to the plant turbines.

Common practice specifies a maximum of 0.25% moisture carryover from the steam generator to the turbines. To stay below this limit designers first minimize the moisture entrained by the steam as it exits from the heat exchanger itself and then remove what moisture there is in carefully designed moisture separators.

Entrainment. As rising steam vapor within the steam-generator tube bundle breaks the liquid surfaces, it carries with it part of the liquid. The amount of entrainment depends upon the steam velocity and the free height above the steam-water interface. Initially, the quantity of liquid entrained is rather large but as the liquid particles are carried upward many agglomerate and fall back down. Thus maximum entrainment occurs at the free surface and gradually decreases until the flow reaches the steam separators.

By equating gravity forces to drag forces for the entrained droplet, one can show that droplets larger than a certain critical diameter will eventually fall back to the free surface if sufficient disengaging height is provided. At steam pressures of the order of 50 psia,

a vapor retention time of 3–5 sec is generally accepted as adequate to avoid overloading the steam-separating gear.

Steam separators. The escape velocities from the steam-water interface are a measure of the steam flow rates to be handled by the separators. Values of the velocity head in commercial designs are not much above 5 ft. Generally low-steam-pressure generator designs use impingement screens for initial separation. Velocities through the screens are between 5 and 10 ft/sec to give a pressure drop of about 0.5 psi. These screens may impart centrifugal action to the steam-water mixture. For reboiler design where the velocity head of the mixture entering the separation gear is relatively low, centrifugal separation does not occur. Closely spaced or corrugated surfaces (sometimes referred to as dryers) usually are the second stage of separation. These dryers can produce the 0.25% moisture content specified for turbine-grade steam. They often consist of tight slots and depend for their effectiveness on more than one change in direction of the moisture laden vapor.

Flow Distribution

In evaluating steam-generator performance, it is not enough to complete a heat-transfer analysis and assume that the installation of sufficient heat-transfer surface will ensure satisfactory operation of the exchanger. The designer must in addition assure an adequate distribution of the steam and water mixture on the shell side of the tube bundle.

Circulation ratio. The commonly accepted measure of the adequateness of the distribution of secondary coolant flow through the tube bundle is the "circulation ratio."

For steam generators the shell-side water circulation ratio is defined as the pounds of water circulating in the unit per pound of steam generated. A small circulation ratio signifies a large percentage of steam in the tube-bundle steam-water mixture and, thereby, poor heat transfer on the shell side. This poor heat transfer in extreme cases can lead to steam blanketing and chemical hideout (deposition) with possible tube failure. The larger the circulation ratio, the more assurance there is that the outside surface of the tube is always wetted. However, this requires greater tube spacing and a larger exchanger.

Reduced circulation is usually the result of pressure losses caused by the steam-water mixture in the riser or tube-bundle section that oppose the differential head available to induce flow. This differential head is produced by the difference in density of the subcooled water in the downcomer section between the tube bundle and the inner surface of the shell. and the steam and saturated water mixture in the tube bundle itself. Data in the literature show a marked decrease in the boiling-heat-transfer coefficient for fractions of steam by weight of 60–80%. These weight fractions correspond to circulation ratios of 1.6 and 1.25 respectively, and represent values that would not be used except in certain very critical cases. More usually circulation ratios vary from about five, at low steam pressures (~100 psia) to 40 at higher pressure (~600 psia).

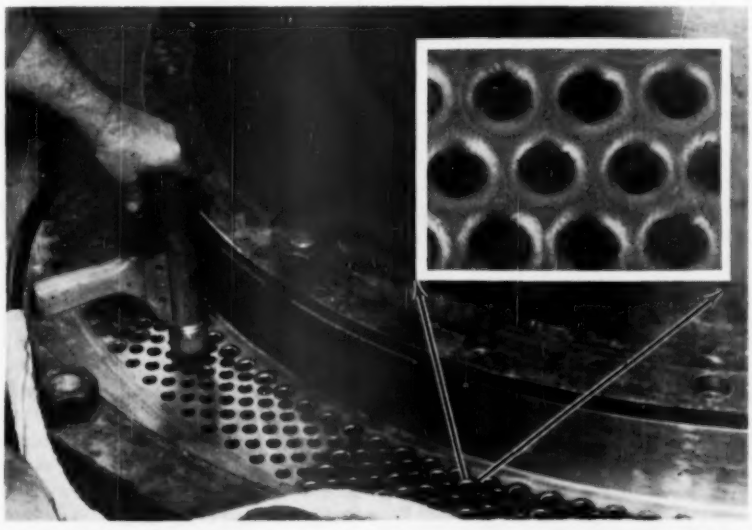
Shell-side flow stability. One of the results of an inadequate circulation ratio is flow instability or oscillations on the shell side particularly in the downcomers and riser sections.

In those instances in which instability is experienced in actual operation, the operator can usually improve the situation by increasing the effective circulation ratio within the exchanger. In the standard steam generator design in which the feedwater is introduced into the shell at or near the bottom of the tube bundle this can be accomplished by increasing the feedwater temperature.

Similarly, tests conducted on vertical low-pressure steam generators similar to those in the Dresden dual-cycle boiling-water reactor plant indicate that the best operating conditions are obtained with exit steam pressure drops of the order of 0.5–1 psi.

Steam blanketing. In some instances, even though the spacing of the tubes allows adequate circulation in the tube bundle itself, it is still possible to have a situation in which the configuration of the shell, usually immediately adjacent to the tube sheet, precludes the free flow of steam to the shell-side outlet nozzle. There stagnant areas lead to improper circulation, instability, steam blanketing and other undesirable conditions. To minimize steam blanketing the tube bundle should not be too tightly packed into the shell, and risers and downcomers spaced sufficiently apart. In a multiple drum generator, the steam-water mixture velocity in the shell should be less than 50 ft/sec to avoid localized steam blanketing.

The steam-generator-tube leaks experienced during the early operation of Shippingport have been attributed to stress corrosion by secondary-side chemicals deposited as the result of steam blanketing in the tube bundle close to the tube sheet. Shippingport alleviated this problem by installing an



1. AUTOMATIC WELDING of tubes to tubesheets gives a more uniformly sound weld than can be achieved with manual techniques; thus the trend is away from manual welding

additional riser adjacent to the tube sheet to provide an adequate flow path for the water mixture leaving the tube bundle at that point.

Transient Performance

So far we have been concerned with the steady-state performance of the main steam generators in the power-reactor cycle. Of equal importance is the stability and operability of steam generators during transient conditions. In actual plant operation, changes in reactor heat output (in response to electric-load changes) are not effective at the steam generators until the primary coolant leaving the reactor has reached the generators.

During this period of time (~10 sec) the turbine governor valve will have repositioned to correspond to the new demand and in turn call for more or less steam from the generators. For increased demand, the pressure in the steam generator and connecting turbine lead piping will fall causing flash steam to be released from the steam-water interface. If the normal level is maintained too close to the top of the tube bundle the sudden flashing of water to steam may uncover the top rows of tubes. Chemicals contained in the water tend to deposit out on tube surfaces exposed in this way which can bring about stress corrosion.

With a sudden decrease in plant load, the closing of the turbine governor valves will cause a rapid increase in steam pressure on the shell side of the steam generator unless an expensive bypass system is installed in the turbine plant to shunt the steam directly to the turbine condenser. This increase in shell-side pressure also produces conditions that cause the steam-water level to fall.

These transient effects do not occur in conventional high-pressure boilers. Lower pressures in pressurized-water-reactor steam generators can permit relatively small pressure changes in the drum to cause wide swings in water level. For example, in a reboiler or single-drum steam generator, the density of the water-steam mixture immediately above the tube bundle may be as low as 15 lbm/ft³ while the density of the sub-cooled water in the downcomer section is 50–60 lbm/ft³. The steam generators for the New Production Reactor at Hanford, which has been designed primarily to produce plutonium with electric power considered a by product to reduce plutonium costs, will operate at a normal steam pressure lower than that in single-purpose power reactors; the manufacturer has predicted the density of the steam-water mixture during normal operations will be less than 5 lb/ft³.

Thermal stresses are the second important limitation on steam-generator transient operation. Although stresses result from thermal gradients associated with steady-state heat flow, the most severe thermal stresses are the result of transient thermal gradients that occur in normal operation (slow power changes, including startups and shutdowns) and, especially, during emergency operations such as scrams and rapid power changes. Operational limitations can be imposed on the tubes, tubesheets, headers, nozzles and internal piping of the steam generator.

Usually, however the most severe thermal shock will be at the steam-generator thermal sleeves during the rapid temperature drops associated with scram transients. The designer can provide sleeves that will withstand the stresses imposed or can try to minimize temperature gradients by increasing natural circulation.

Primary-coolant inlet nozzles and heads also undergo severe thermal shocks since they represent rather large heat sinks exposed to rapid temperature changes and have stress concentrations located at points of maximum thermal gradient. Outlet heads and nozzles for the primary coolant are subjected to far lower thermal stresses than those at the inlet because of the damping effect during coolant passage through the tubes.

For detailed discussions of thermal-stress calculations see the Bureau of Ships report "Tentative Structural Design Basis for Reactor Pressure Vessels and Directly Associated Components," (Pressurized Water Cooled Systems December 1958 revision).

MAINTENANCE

To reduce the costs of maintaining the steam generator equipment in operating condition over plant life, designers are giving more and more thought to provisions that facilitate units and minimize downtime required to make repairs. With nuclear steam generators, the most common cause of forced outage for repairs is leaking tubes.

Because of the less stringent water chemistry the trouble usually starts on the secondary side. The easiest way to detect leaks in pressurized water installations is to monitor the radiation level of the secondary coolant. During normal operation, the higher pressure maintained in the primary system causes fluid to leak from the primary to the secondary side when a tube fails. Because of the high degree of water purity maintained in the primary system, one cannot detect the leakage through conductivity measurements of the secondary fluid. In addition, the leakage rates during the early stages are usually too low to cause a detectible change in primary system inventory. However, the increase in radiation level of the secondary system offers a most reliable method of detecting the presence of primary water.

Establishing the presence of a leak is only half the problem; the leak must then be located and plugged. For a major tube failure one can accomplish this by removing the generator from the line and draining the primary side while flooding the secondary side and possibly pressurizing it with an inert gas to approximately 100 psi. After decontamination, visual inspection of the primary-side tubesheet to locate the source of water from the secondary side indicates which tube has failed.

Minor leaks are not often this easy to locate. Frequently, a leak that can be detected during normal operation will seal itself when the unit is shutdown. This happens because the tubes contract with reduction in temperature and the pressure differential between the primary and secondary sides differs from that during operation. Leaks of this kind can be detected by examining individual tubes visually with a borescope; however, this is a time-consuming process and extremely difficult unless the design of the steam generator provides easy access to the primary face of the tubesheet.

The problems associated with this type of maintenance were highlighted by the repairs made on the leaks discovered during the initial phases of operation at Shippingport. In attempting to locate and plug leaking tubes through hand holes, the maintenance personnel were exposed to maximum allowable radiation dosages on their hands and arms. Inspection and access openings adequate for maintenance personnel to quickly locate and repair any leaks or other problem areas

should be incorporated in the design of all nuclear steam generators.

MATERIALS AND FABRICATION

To date, the materials most frequently used in nuclear steam generators are the type 300 series austenitic stainless steels. These materials exhibit low corrosion rates (~5 mg/dm²/month) in the presence of primary coolant water at 500 to 600°F. Moreover, austenitic stainless steels can be readily produced in which undesirable trace elements are held to predetermined maximum concentrations. For example, the cobalt content of stainless steel can be maintained below 0.05%; this is low enough to keep the amount of radioactive Co^{60} in corrosion products to acceptable values. For economy, it has been the practice to substitute stainless-steel-clad carbon or low-alloy steel for stainless steels in heavy sections. The combination of these materials within the same equipment poses the problem of exposing the austenitic stainless steels to sensitization temperatures while stress-relieving the ferritic-steel welds. One can alleviate this problem by choosing the extra-low-carbon and stabilized grades of austenitic stainless steels such as types 304L and 347. In other instances, type 304 stainless has been successful with a low-temperature stress relief (950–1,050°F).

Because the austenitic stainless steels are susceptible to stress corrosion, one must take care to maintain the secondary-side water chemistry within allowable limits (*10*).

Although austenitic stainless steels were used for the entire primary side in earlier nuclear steam generators, recent designs have been turning to less expensive ferritic steels. To date, ferritic steels have been used principally as the strength member of clad composite steels for tubesheets and primary side channels and for the secondary side components, such as the shell and heads. For these applications, the ferritic steels are treated either by the addition of aluminum during melting or by heat treatment of the wrought product to prevent the possibility of brittle failure.

In the steam generators for the New Production Reactor at Hanford, carbon steel is replacing stainless steels in direct contact with high temperature, radioactive water. The steam generators for the NPR use unclad carbon steel for inlet and outlet heads and connections and other primary side components. Type 304 stainless steel is employed for tubing and for cladding the primary-side face of the tubesheet to facilitate the tube-to-tubesheet welds.

Exposure of this combination of austenitic and ferritic materials to the primary coolant poses a problem, for present data indicate a corrosion rate for carbon steel 7½ to 10 times higher than that of austenitic stainless steels. An inert atmosphere must be maintained within the steam generators during nonoperating periods to prevent localized corrosion and pitting. In addition, the decontaminant chemicals used to remove radioactive corrosion products from both materials must not bring about localized corrosion effects. The cobalt content of the ferritic steel should be quite low. Steel with less than 0.02% cobalt is presently available.

The nickel base alloy Inconel is also finding increasing use in nuclear heat exchangers. For instance the Carolina-Virginia Tube Reactor will have Inconel tubes in the steam generator. From the standpoint of corrosion, Inconel is considered equal to stainless steels with the added advantage that it is not susceptible to stress corrosion cracking. But Inconel welding techniques are still being developed to facilitate tube-to-tubesheet welding.

Fabrication Practice

The essential parts of a nuclear steam generator can be put into two classes: the primary-side components consisting of the tubesheet, tube bundle, head and nozzles and the secondary-side components consisting of the shell, shell baffles, heads and nozzles.

Primary side components. Tube sheets are made from forgings or rolled plate. Both flat and cylindrical tubesheets are in use. Sizes based on present experience range up to 14 in. in thickness and 54 in. in diameter for the more common flat sheets. The stainless-steel cladding is applied to the primary face of the tubesheet by either an integral roll bond or weld deposition. The heavy tubesheet sections require extra caution in their manufacture to avoid widespread areas of nonmetallic inclusions; this is a special problem for aluminum-treated steels for which impact properties are specified.

Tube holes are, typically, drilled and reamed to a 125 μin. rms surface roughness by tape-controlled gang-drilling machines.

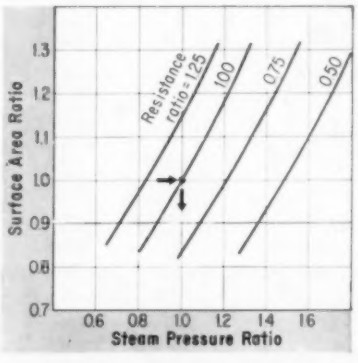
Tubing. Predominantly tubing has been seamless; however, more recently at least two land-based power-reactor systems (Dresden and NPR) have used welded tubing. The flat strip from which the welded tubing is formed can be inspected from both sides whereas the internal surface of seamless tubing must undergo a time-consuming and costly visual inspection with a borescope.

In lengths of 30 ft and over welded tubing becomes particularly attractive both in price and number of sources of supply. Considerations that limit tubing lengths are the availability of cold-drawing equipment, special handling equipment, large-capacity pickling tanks and the inherent risk of manufacturing a longer tube than is used conventionally.

Available sizes of high-alloy tubing for nuclear heat exchangers range up to 60 ft in length. Tube diameters commonly range from 0.50 to 0.75 in. with wall thicknesses in the vicinity of 0.050 in.

Tube-to-tubesheet welding. The practice has been to seal the radioactive primary fluid from the secondary fluid by welding the tubes to the tubesheet. Such welds vary, depending on the operating conditions, from seal welds to full-strength welds. Prior to welding, the tubes are rolled into the tubesheet. This operation serves to provide optimum fit up for welding and reduces the crevice formed between the tube and the tubesheet.

The tube-to-tubesheet weld can be



2. HOW TOTAL THERMAL resistance (not including outside boiling film resistance) affects steam pressure and required area of tubes for water-reactor steam generator

Main Heat Exchangers in Water-

Reactor	Date installed / Service (mos.)	No. / Function	Primary side (per ea.) Heat load (10^6 Btu/hr) / Flow (10^6 lb/hr)	Design (°F / psi)	Operating °F in / psi in	Operating °F out / psi out	Steam drum	No. fluid passes, shell / Tubes	Tubing position / Shape
Pressurized-Water-Cooled Power Reactors									
Yankee	12/59	4	347	650	528	500	Integral	1	Vert.
	9+	Primary	10.5	2,485	1,990	1,965		2	U-tube
Indian Point	3/60	4	499	650	519	486	Separate	1	Horiz.
	(11/61)	Primary	13.2	1,515	1,500	1,449		1	U-tube
N.S. Savannah	5/59	2	126.3	650	521	495	Separate	?	Horiz.
	0	Primary	4.0	2,000	1,750	1,732		1	U-tube, shell
NPD	11/60	1	270	650	530	485	Separate	1	Horiz.
	0	Primary	5.4	1,200	1,030	1,009		1	U-tube, shell
CANDU	(63)	80 (8 drums)	28.2	570	560	480	Separate	1	Vert.
	0	Primary	0.302	1,362	1,305	1,290		1	U-tube, shell
R3/Adam	(8/61)	4	79	480	428	401	Integral	?	Vert.
	0	Primary	0.5	580	480	450		?	U-tube
APPR-1(SM-1)	10/56	1	34.1	650	450	432	Integral	1	Vert.
	48+	Primary	1.656	1,600	1,500	1,493		2	U-tube
APPR-1A(SM-1A)	12/59	1	68.5	600	443	423	Integral	1	Vert.
	0	Primary	2.78	1,500	1,200	1,193		2	U-tube
PM-1	(?)	1	32	600	479	447	Integral	1	Vert.
	0	Primary	0.847	1,500	1,300	1,285		1	U-tube
PM-2A	8/60	1	34.7	600	518	500	Integral	1	Horiz.
	7+	Primary	1.665	2,000	1,750	1,744		2	U-tube
PM-3A	(?)	1	32	600	479	447	Integral	1	Vert.
	0	Primary	0.847	1,500	1,300	1,285		1	U-tube
NPR	5/61	?	?	600	?	?	Integral	1	Horiz.
	0	Primary	?	1,825	?	$\Delta p = 36.2$		2	U-tube
PRTR	12/59	1	225.26	600	530	487	Integral	1	Horiz.
	0?	Primary	3.72	1,250	1,087	1,067		2	U-tube
HWCTR	2/61	2	104	550	432	392	Integral	1	Vert.
	0	Primary	2.6	1,515	1,015	1,002		2	U-tube
Boiling-Water-Cooled Power Reactors*									
VBWR	5/57	1	146	600	544	433	Separate	1	Vert.
	?	Secondary	1.5	1,315	1,015	1,008		2	U-tube
Halden	10/58; 61	1, 2	3.42	482	?	446	Separate	?	Horiz.
	12+	Primary	0.05	588	400	?		?	U-tube
Kahl	7/60	1	169	574	546	546?	Integral	1	Vert.
	0	Primary	0.261	1,250	1,000	1,000		1	Straight
Elk River	11/60	2	85	572	538	536	Integral	1	Horiz.
	0	Primary	0.129	1,250	936	936?		2	U-tube
Elk River	11/60	2	13.5	572	536	450	None	1	Horiz.
	0	Subcooler	0.129	1,250	936	934		2	U-tube
SENN	(62)	2	209	576	530	508	Integral	1	Vert.
	0	Secondary	9.256	1,290	1,065	1,050		2	U-tube
Spert-2	?	1	?	?	?	?	N.A.	1	Horiz.
	?	Dump to air	?	?	?	?		4	Straight
Spert-3	9/58	2	102.3	668	650	212	Separate	1	Horiz.
	31	Primary	0.2675	2,515	2,515	2,505		2	U-tube
Spert-4	Now	1	4.05	130–	100	98	Integral	1	Vert.
	0	Primary	2.1	90	90	80		1	Straight
Aqueous Homogeneous Power Reactors									
HRE-1	1/52	1	3.415	482	482	407	Integral	1	Horiz.
	15	Primary	0.0419	2,015	1,015	982		1	U-tube
HRE-2 (blanket)	10/56	1	1.7–10.9	575	527–473	518–392	Integral	1	Horiz.
	20	Primary	0.09	2,000	1,250–1,750	1,231–1,731		1	U-tube

* The Bonus, Sioux Falls, Humboldt Bay, Big Rock Point, Japan BWR, Borax-5, and VSR boiling-water-cooled-reactor plants have no primary heat exchangers (limited to feedwater heaters and condensers). Spert-1 heat removal is only by natural convection. † These 16-ft-long tubes have 0.625-in.-high fins (7/in.) Al-soldered to tubes. ‡ Dimensions and weight applies to each assem-

Cooled Power-Reactor Systems

Tubes (per ea.)			Heat-transfer surface (ft^2)	Shell		Secondary feedwater	Size (~ft)	Manufacturer	
No. tubes / Bundles removable	I.D. / O.D. (in.)	Wall (in.) / Material	Fouling resistance $\left(10^{-4} \frac{hr\ °F\ ft^2}{Btu}\right)$	I.D. / O.D. (in.)	Wall (in.) / Material	$\left(\frac{°F}{psia}\right)$	L / D or H/W	Dry weight with drum (~lb/ea) / Cost (~$/ea.)	Reactor
1,620	0.606	0.072	13,430	78.75	3.12	320	40.2	Westinghouse	Yankee
Yes	0.750	304ss	3	85	A212B	820	8.5	187,200/553,000	
811	0.876–	0.062+	13,375	46	1	330	39.9	Babcock & Wilcox	Indian Point
No	1.000	ss	3	48	?	420	21.5/12.7	192,480/?	
812	0.606	0.072	4,050	35	0.109/1.141	345	20.2	Babcock & Wilcox	N.S. Savannah
No	0.750	304ss	3	37.5	304ss/C steel	455	17.1/9.3	71,000/?	
2,069	0.400	0.050	5,700	38	0.875	300	23	B&W + Goldie-McCullough	NPD
No	0.500	Inconel	3	39.75	C steel	425	14/22	68,000/250,000	
195	0.402	0.049	1,070	10.02, 13.00	0.365, 0.5	340	21‡	Montreal Locomotive Wks	CANDU
No	0.500	?	3.3	10.75, 14.00	A106B	594	32.5/7.5	68,600‡/?	
?	0.32	0.04	18,000	?	?	240	33	§	R3/Adam
Yes	0.4	?	6.7	?	C steel	350	4.3	60,000/?	
370	0.626	0.062	1,030	46.62	0.125+/0.187	246	19.8	Alco Products	APPR-1
No	0.750	304Lss	3	47.25	304Lss/C steel	200	4	22,500/?	
498	0.750	0.062	1,725	47.87	0.187/0.625	250	18	Alco Products	APPR-1A
No	0.875	430ss	3	49.5	304Lss/C steel	200	4.2	21,700/?	
?	0.370	0.065	1,100	?	?/?	311	17.8	Westinghouse	PM-1
No	0.500	?	?	?	304ss/C steel	300	2.8	9,600/?	
263	0.750	0.062	897	48	0.25/1.06	?	4	Alco Products	PM-2A
No	0.875	304ss	2.5	50.62	304ss/C steel	?	7/3	18,100/?	
?	0.370	0.065	1,100	?	?/?	311	17.8	Westinghouse	PM-3A
No	0.500	?	?	?	304ss/C steel	300	2.8	9,600/?	
1,916	0.527–	0.05	16,000	120	3	?	57	Combustion Engineering	NPR
No	0.625	304ss	3	126	C steel	?	10.5	335,000/450,000	
1,858	0.402	0.049	6,915	111.12	1.435	200	16	Yuba Consol. Ind.	PRTR
Yes	0.500	304ss	5	114	A302B	425	9.5	69,800/153,000	
611	0.532	0.109	2,500	48	1.125	344	23.2	M. W. Kellogg	HWCTR
No	0.750	C steel	5	50.25	C steel	125	4.2	37,800/40,000	
800	0.416	0.042	1,725	37	0.625	365	24.2	Foster-Wheeler	VBWR
?	0.500	ss	?	38.25	C steel	?	5.6	20,000/42,000	
?	0.63	0.079	1,423	32.2	0.59	?	16.4	Thune's (Oslo)	Halden
Yes	0.79	17Cr 1.7Mo1C	?	33.4	18-8ss	?	5.6	?/?	
1,769	0.906	0.098	8,500	67	0.26/2.6	?	39.2	Phoenix-Rheinrohr AG	Kahl
No	1.103	?	?	72.8	304ss/C steel	665	8.2	208,000/?	
642	0.620	0.065	4,710	50	1.65	458–525	23.5	A. O. Smith	Elk River
No	0.750	304ss	5	53.3	C steel	705	4.5	43,200/50,500	
70	0.620	0.065	369	16.12	?/?	350–458	15.3	A. O. Smith	Elk River
No	0.750	304ss	5	?	304ss/C steel	715	2.7	5,900/9,928	
1,785	0.599	0.075	4,630	88	0.25/3.0	375	23.6	¶	SENN
No	0.748	?	3.5	94.5	Monel/C steel	500	7.9	120,000/?	
82	0.870	0.065†	6,130†	N.A.	N.A.	N.A.	?	Smithco Engineering	Spert-2
No	1.000	304Lss	10				?	?/11,550	
367	0.495	0.065	1,940	64.125	0.437	58	20	A. O. Smith	Spert-3
Yes	0.625	304ss	10	65	A212A	90	7.2/5.5	22,400/?	
320	0.652	0.049	580	19.25	0.375	58	14.3	Manning & Lewis Eng.	Spert-4
No	0.75	304ss	10	20	C steel	40	4	3,000/8,525	
112	0.152	0.049	72	26.25	0.875	100	6	A. O. Smith	HRE-1
Yes	0.250	?	2	28	?	210	2.3	3,200/5,400	
250	0.245	0.065	480	36	1.375	180	14.1	Foster-Wheeler	HRE-2
No	0.375	?	3	38.75	?	225–850	3.3	13,400/40,000	

bly of 10 heat exchangers with one drum. § Two were made by AB Rosenblads Patentor and two were made by Jonkopings Mek. Werkstads AB. ¶ Koninklijke Machinefabriek Gebr. Stork & Co. NV, Hengeloo, The Netherlands. For more data on these and other reactors, see NU, Nov. '60 p. 148.

made either manually (shielded metal arc, coated electrodes) or by an automatic process (inert-gas-shielded tungsten-arc). The trend is away from manual welding and toward automatic processes (see Fig. 1) for tube-to-tubesheet welding.

Secondary-side components. In pressurized- and boiling-water steam generators, the secondary-side pressures are considerably lower than those of the primary side.

The shell is made from rolled plate and in the larger steam-generator sizes the shell is composed of two or more plates which are first rolled and welded along a longitudinal seam and then welded to each other along a girth seam. Welded joints are full penetration, double-V butt type. The shells for the Hanford steam generators—the largest built to date—are 10 ft in diameter by 60 ft long.

At present, secondary-side shell openings are also seal welded although this requirement will probably be relaxed in the future.

Because of the numerous welds involved in the completed unit, subassemblies are sometimes given an intermediate stress relief prior to the final vessel stress relief to minimize welding stresses.

Code requirements. Fabrication procedures in general conform to the existing ASME codes. These rules for manufacturing code vessels for nuclear service are covered in Case No. 1270 N, "General Requirements for Nuclear Vessels" and Case No. 1273, "Nuclear Reactor Vessels and Primary Vessels." The special rulings list as mandatory several fabrication procedures, which for conventional heat exchangers are left to the discretion of the manufacturer. These requirements include:

- All longitudinal and circumferential joints must be welded from both sides
- Heat exchangers manufactured from ferritic steel must be stress-relieved regardless of shell thickness
- At vessel-nozzle connections, compensation required for openings must be integral with the heat exchanger shell or nozzle. This provision eliminates reinforcing saddles. Moreover, self-reinforced nozzles must be joined to the shell by full penetration welds unless the location of the nozzle precludes this type of construction
- All strength welds subject to pressure must be radiographically inspected to code standards. If this is not feasible the radiographic inspection must be performed to the extent that the location of the weld allows, or other nondestructive tests, such as liquid penetrant or magnetic particle, must be substituted
- When different materials are used to act as cladding for protection of the base metal against corrosion, no allowance can be taken for the thickness of the cladding material when calculating the required thickness of the base material.

Symbols

A_o	Surface area (ft^2)
c_p	Specific heat (Btu/lbm-°F)
D	Diameter (ft)
f	Fouling factor (°F-ft^2-hr/Btu)
G	Mass velocity (lbm/sec-ft^2)
h	Average heat transfer film coefficient (Btu/hr-ft^2-°F)
k	Thermal conductivity (Btu/hr-ft-°F)
m	Mass flow rate (lbm/hr)
q	Heat transferred per unit time (Btu/hr)
r	Radius (ft)
T	Temperature (°F)
U	Over-all heat transfer coefficient (Btu/hr-ft^2-°F)
μ	Viscosity (lbm/sec-ft)

Subscripts

b	Bulk
i	Inside
lm	Logarithmic mean
m	Mean
o	Outside
p	Primary
s	Scale, steam
t	Tube
w	Wall

Fabrication and Quality Control

The most rigid inspection is performed on tubing. Inspection techniques usually specified for seamless tubing include visual, ultrasonic and liquid-penetrant testing. Welded tubing, in addition, is radiographically examined for the full length of the weld. Straight tubing subjected to such testing commands a price generally 30–40% greater than comparable commercial quality tubing. Approximately 60% of this additional cost lies in ultrasonic testing, 20% in liquid penetrant testing and ~20% for radiographic inspection. Despite the additional radiographic inspection cost, welded tubing is competitive with seamless tubing, particularly in lengths greater than 30 ft.

Tubing producers are now offering eddy-current testing as a cheaper means of tubing inspection. The technique appears best for small-diameter tubing (⅝ in. in diameter or less) of nonmagnetic materials. It has been successfully applied to welded tubing sufficiently cold worked to refine the structure of the weld. At present, the authors know of no application in which eddy testing has been used as a substitute for ultrasonic testing on tubing for nuclear steam generators.

Neither the tube-to-tubesheet weld nor the weld-deposited cladding can be inspected radiographically. Accordingly, accepted practice depends on the liquid-penetrant test for the examination of weld quality.

The strength welds of ferritic steels in nuclear steam generators receive both magnetic particle* and radiographic examination. Magnetic particle examination is performed on the root pass and the surface of the completed weld.

Cleanliness standards for the manufacture of nuclear steam generators are much severer than those for conventional commercial equipment. Generally the specifications require that all visible foreign material be removed. Consequently, shop practices are carefully controlled to prevent contamination of subassemblies with shop dust during manufacture. In naval applications special clean rooms or clean areas are required for final assembly operations.

TRENDS IN COST OPTIMIZATION

By following the practices outlined in the preceding sections, engineers have succeeded in designing and fabricating nuclear steam generators that transfer heat at the required rate with a reliability that promises to be satisfactory (as far as can be predicted) over plant lifetime. But so far the steam generators built according to these methods are much too expensive. The major problem confronting steam-generator designers today is how to cut the costs of these components and at the same time hold performance and reliability at acceptable levels.

Let us compare the cost of nuclear steam-generating equipment with that of nonnuclear equipment of similar size and operating conditions. A non-

* In this test iron powder dusted over the test area in the presence of a magnetic field reveals distortions in the magnetic lines of force caused by inhomogeneties in the weld. Test works only for magnetic materials.

nuclear shell-and-tube generator with ~7,000 ft² of carbon-steel heat-transfer surface, producing 400 psi steam and with tubes rolled into the tubesheet and the shell fabricated in accordance with the ASME code for Unfired Pressure Vessel would cost approximately $5–$7 per square foot of surface. A comparative nuclear steam generator designed for the same temperature and pressure conditions, containing 7,000 ft² of stainless-steel tubes welded to the tubesheet and designed in accordance with nuclear code requirements, would cost approximately $20–$40 per square foot.

The wide spread in quoted cost for the nuclear steam generator is directly chargeable to variations in standards of quality control and cleanliness. As we have seen, these range from standard commercial practice as modified by nuclear-code requirements to the clean-room approach for naval nuclear vessels.

Aside from these costs, the difference in cost between the nonnuclear and the nuclear shell-and-tube steam generators can be traced to

- The use of stainless steel for the tube material
- Welding of the tubes to the tubesheet
- Changes in shell design and fabrication to provide for complete radiography of all pressure welds
- Increased engineering charges owing to lack of standardization.

Hence we can expect cost savings to come (a) through a gradual relaxation of the present rigid design and quality-control practices (when justified by operating experience) and (b) through new developments and improvements in steam-generator design, fabrication or metallurgy.

Thermal Efficiency

One approach to improving costs is to explore ways to increase the thermal rating by reducing the total thermal resistance.

The resistance represented by the inside film coefficient can be reduced at the expense of extra pumping power to increase tubeside velocity. For the example quoted in the table on p. 72, if the velocity were raised from 12.5 to 20 ft/sec the resistance would decrease to 0.000132° F-ft²-hr/Btu for a net decrease in total thermal resistance of 5.5%.

If the tube material were changed from stainless steel to carbon steel and at the same time the wall thickness doubled to allow for the increased corrosion rate of carbon steel, the tube-metal resistance would decrease to 0.000290°-Fft²-hr/Btu for a net decrease of 12.5% in total thermal resistance.

If the secondary-side fouling factor were reduced or completely eliminated, a total potential reduction in thermal resistance of 25% would be possible. Justification for reducing this fouling factor can be obtained only through tests on units presently being placed in service to determine the degree of secondary-side fouling that occurs during actual operation. Admittedly tests of this type are expensive to perform but the possible savings on future installations would appear to warrant the expenditure.

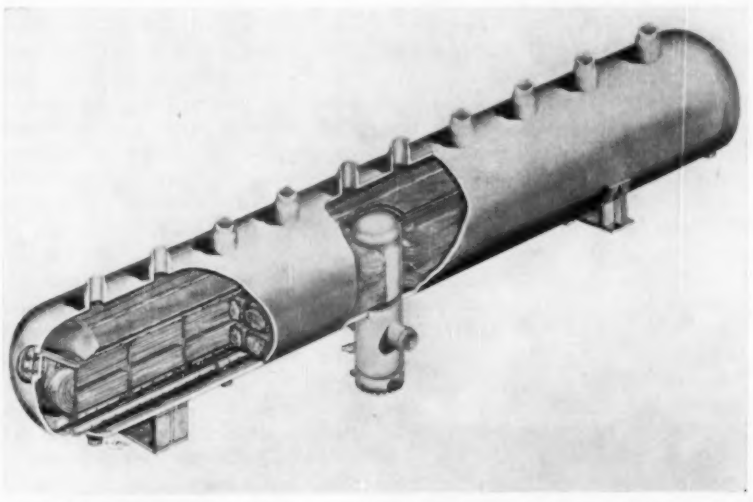
Any decrease in secondary-side boiling film resistance awaits compilation of operating data by both manufacturers and operators. The prospects of getting the needed data from full-scale operating units in the field are not encouraging if we judge by past experience. Traditionally operators, once their steam generators are built and working, have been reluctant or at least not strongly motivated to gather the sort of detailed information required. Manufacturers may finally have to build and operate small experimental units to provide the fund of data needed to design for lower boiling-film resistance.

Figure 2 shows the effect on secondary steam pressure and required steam-generator heat transfer area of different combinations of total thermal resistance.

Optimum Physical Size

In conventional power-plant practice there is apparently no end in sight to the current trend of increased unit size. But in going to larger sizes for nuclear units we face a point of diminishing returns. The boiler-pressure tubes for steam-generating equipment in fossil-fuel plants can be erected *in the field*. Because of the requirements for cleanliness and quality control, the nuclear steam generators furnished to date have all been *shop assembled*, complete with tube bundles, and shipped intact to the plant site. Admittedly for multiple drum units, the steam drums have been shipped separately for field assembly and welds on the secondary-side risers and downcomers completed in the field. However, the necessity for shop fabrication of the primary side definitely limits the size of individual steam-generating units.

This limitation on ultimate size of shop-fabricated units manifests itself in many ways. For the single-drum or reboiler generator, the shell diameter required to provide steam-separation volume poses a transportation problem as well as a shop-fabrication problem because of physical size and weight. For multiple-drum units present-day limitations on tube length and the size of shop stress-relieving furnaces, as well as equipment crane-handling



3. UNIQUE CYLINDRICAL tubesheet at center (rather than a flat one at either end) of NPR steam-generator shell minimizes thermal stresses in tubesheet and gives effect of two heat exchangers in one shell. Design is significant innovation in field

capacity, limit the size of individual units. Another limitation that affects both types of generators is the relationship of tube-bundle diameter to tubesheet thicknesses. Increased tubesheet thickness poses several design problems particularly in the area of thermal stresses as well as many fabrication problems that range from the manufacture of the tubesheet forging, and the problem of drilling true holes for the tubes, to the handling of the tubesheet during the entire fabrication process. We can predict, then, that the trend of decreasing unit cost with increasing steam-generator size will start to reverse itself as the size approaches and exceeds that which the manufacturers' normal shop facilities are designed to handle.

Design Configuration

So far we have considered only the cost trends that affect steam generators without considering the interaction with other items of plant equipment. One important way in which steam-generator design interacts quite directly with over-all plant costs is in the cost of space to house the exchangers. The over-all space requirements of the generator assembly directly affects the extent of shielded area required, which in turn affects the confinement volume. Since the steam-generator arrangement must be coordinated with the over-all plant layout, it is difficult to assess the relative cost aspects of the space requirements for different types of steam generators without reference to a specific reactor-plant installation. One can say, however, that for a given thermal output vertical steam generators require less space than horizontal units. On the other hand one can provide greater capacity in a single-drum horizontal unit than in a vertical unit because of the limits imposed on the vertical unit by the need for steam separating space at the top. Hence the relative space requirements of a multiple-unit vertical-exchanger installation versus a single-unit horizontal-exchanger installation are difficult to predict.

One can also make the general observation that a multiple-drum steam generator requires more space than a single-drum or reboiler unit. However, this statement, too, must be modified. At relatively low levels of secondary steam pressure, one may obtain greater capacity from a multiple-drum unit, because the shell diameter for a single-drum unit may be limited by either shop or transportation facilities.

To complete the categories of steam generators mentioned earlier, we can say that a horizontal straight-tube unit usually requires more space than a U-tube unit not only because it is longer for a given thermal rating but also because more space is needed for tube-removal operations.

The NPR steam generators (Fig. 3) serve as an example of how innovations in tubesheet configurations can lead to savings. In radical departure from the conventional flat plates, the NPR tube sheets form sectors of the cylindrical manifold at the center of the heat-exchanger shell. This arrangement minimizes thermal stresses in the tubesheets and gives in effect two heat-exchanger units in one shell.

Material and Fabrication Costs

As an indication of the relative contribution of material and fabrication costs to the final steam generator price, the following tabulation shows the fraction of the total material and fabrication costs allocated to each item.

Item	*Per cent*
Tube material	26.5
Heads and secondary-side shell	24
Primary-side cladding	2.5
Steam separators and miscellaneous accessories	4
Quality control	17
Nuclear cleanliness standards	6
Complete shop assembly	20

The tabulation is for a single-drum or reboiler steam generator with seamless stainless-steel tubes, a stainless-clad primary-side inlet and outlet head assembly and carbon-steel-shell and secondary-side nozzle connections. The generator design complies with nuclear code requirements and includes steam-separating equipment and standard accessories such as level indicators.

Welded tubes offer a reduction in tube cost in the longer tube lengths. The magnitude of these savings approach 6% of the total cost of the steam generator allocated to materials and fabrication. Eddy-current inspection should lower costs even further.

As experience is gained with carbon steel in primary-loop service, we can foresee its use in the tube bundles themselves with a resultant saving in initial cost and elimination of chloride-stress-corrosion problems. Seamless and welded carbon-steel tubing is currently in use for conventional steam boiler and superheater tubes in thicknesses of at least 0.085 in. This thickness is greater on a strength basis than is needed for current operating conditions in nuclear steam generators. The extra thickness will, therefore, provide for the higher corrosion rate. The substitution of carbon-steel tubes in place of the stainless-steel tubes would result in a net savings approaching 12–15% of the steam-generator costs chargeable to materials and fabrication. Conversely, based on present data, the substitution of tubes made from Inconel would result in an equivalent increase in cost of approximately 15–20%

Although not included in the tabulation, engineering costs can approach a value of 40% of the total exchanger costs for some of the smaller highly specialized steam generators purchased to date. Many generations of power reactors may be required before there is enough standardization to yield substantial reductions in the cost of these design services.

The trend toward automatic welding processes to make the tube-to-tubesheet welds provides one example of how inspection requirements may eventually be relaxed. When fabricators accumulate enough experience with standardized automatic processes to demonstrate a consistently high weld reliability, the present dye-penetrant test can be discontinued and only visual inspection employed.

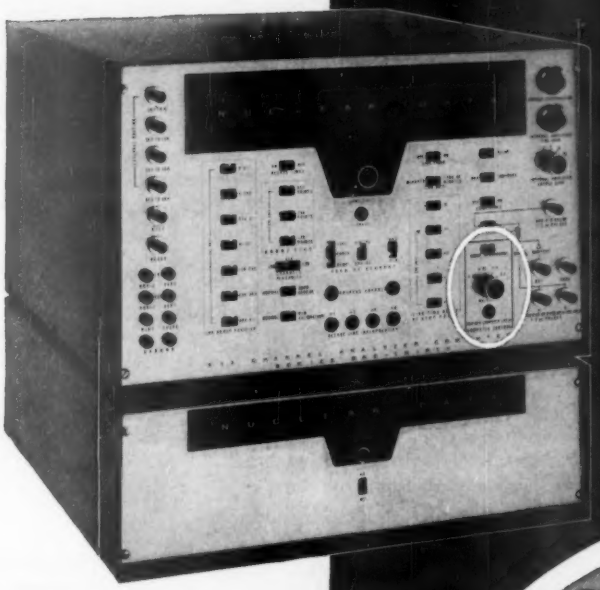
* * *

For illustrations of equipment and for discussions of steam-generator design and fabrication techniques, the authors wish to thank Combustion Engineering Inc., Babcock & Wilcox Co. and Griscom-Russell Co. The authors also wish to thank G. M. Oldham, Charles Jones and Joseph Cash of Duquesne Light Co. for helpful discussions on operating experience at Shippingport.

BIBLIOGRAPHY

1. A. J. Grom. Mechanical design of heat exchangers, *Ind. Eng. Chem.* **52**, No. 6 (1960)
2. D. S. Morton. Thermal design of heat exchangers, *Ind. Eng. Chem.* **52**, No. 6 (1960)
3. C. F. Bonilla, "Nuclear Engineering" (McGraw-Hill Book Co., Inc., New York, 1950)
4. W. H. Giedt, "Principles of Engineering Heat Transfer" (D. Van Nostrand Co., Inc., Princeton, N. J., 1957)
5. D. Q. Kern, "Process Heat Transfer" (McGraw-Hill Book Co., Inc., New York, 1950)
6. W. Hyrnisak, "Heat Exchangers" (Academic Press, Inc., New York, 1958)
7. W. M. Rohsenow, "Heat Transfer, A Symposium" (University of Michigan Press, Ann Arbor, 1953)
8. H. K. Forster, N. Zuber, Conference on Nuclear Engineering (Los Angeles, 1955)
9. I. Granet, *J. of Amer. Soc. of Naval Eng.* (May, 1959)
10. W. L. Williams, J. F. Eckel, Stress corrosion of austenitic stainless steels in high temperature waters

ANOTHER STEP.....



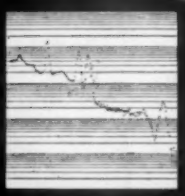
Internal data reduction is another new step by Nuclear Data

Less obvious at a glance, but even more significant, are the steps taken before automatic digital data reduction could even be applied.

The linearity, stability, measurement resolution, and experiment timing accuracy are better than anything we've seen yet. These are big steps for gamma applications, and vital for high resolution particle analysis.

Simple, dependable punched tape controls for *both* read-in and read-out, precise logarithmic CRT display and pen recording, and typewritten digital read-out are standard features of the model ND 130T Analyzer, and these are all provided by *internal* analyzer circuits.

Here is the finest analyzer in the field.



Write Department 512 for our new 24 page general catalog.

NUCLEAR DATA INC.

3833 WEST BELTLINE HY.
MADISON / WISCONSIN

Scintillating Beads for Aqueous Solutions

One way to combine the advantages of liquid scintillators and plastic scintillators is to make scintillator beads. Since the beads can be poured from one container to another, they can, like a solid plastic, be shaped to fit the problem. Since they offer large surface area per unit volume (they are ½ mm in diameter, ½ mm long), they offer intimate contact between scintillator and sample as does a liquid-scintillator system. An advantage over liquid-scintillation counting is that one is not limited to hydrocarbon-soluble systems as one generally is with liquid scintillators.

The beads, which are made by Pilot Chemicals, are more than two years old now. During their lifetime they have found some interesting uses. For example, Robert E. McMahon of Lilly Research Laboratories reports that his company has been using them to count radioactive carbon dioxide from breath samples. The gas is trapped in simple bubblers and presented to the beads in an alkaline water-alcohol solution. The method is faster and more convenient than other conventional methods.

Another user, A. Beerbower of Esso Research and Engineering Co., reports an experiment to determine the oil-water-partition coefficient of a lubricant additive. Specific activity of the S^{35}-labelled additive was evaluated with a liquid scintillator, and the beads were calibrated with a C^{14} standard. C^{14} and S^{35} have similar spectra. 2×10^{-4} cm³ of additive was dissolved in 0.1 cm³ of 5% sodium hydroxide and then diluted with 1 cm³ of isopropanol. Addition of 4 cm³ of counting beads produced an absolute counting efficiency of 12.6%, about one fifth of the efficiency of the liquid-scintillation counter. A similar experiment with tritium gave a disappointing efficiency of only 2.2%.

Another application is the assay of effluents from a gas-chromatograph column (see NU, May '61, p. 45). Beads are poured into a plastic spiral which serves both as a container of the flowing gas and as a light pipe. Ralph Monaghan of Well Surveys, Inc., reports that his company is using the beads for fast-neutron detection in well logging.

In general the beads are reusable after cleaning although Beerbower reports that since he cannot decontaminate the beads well enough, he reuses them only after the decay of 87-day S^{35} has reduced contamination to a level that does not interfere.

Temperature, Humidity and Films

Beware high humidity if you are reading film badges, especially if the film packets have not been protected by impermeable plastic. Even polyethylene bags that are customarily used are not good enough protection if you want accuracies of a few per cent. The effect of high humidity is considerably greater at higher temperatures.

These are among the conclusions of Margarete Ehrlich, who has been investigating temperature and humidity influences with a carefully controlled set of experiments at the National Bureau of Standards. In a temperature-controlled room different humidities (~12–98% relative to saturated air) are created by putting solutions of different salts in closed glass jars. In each glass jar are hung both bare and polyethylene-protected films (Du Pont 502–485), and all are exposed to a small Co^{60} source for about a month. Controls in dry jars and polyethylene bags are exposed at usual room temperature to a larger source a few days before the end of the test exposures. All films are stored in a refrigerator for five days after exposure and then developed. To test the temperature effect, Miss Ehrlich performed the experiment three times—at 5.5°C, 20°C and 32.5°C.

Relative sensitivities (reciprocals of doses required for density of control) for bare film packets varied from 0.96 (5.5°C, 75% relative humidity) to 1.45 (32.5°C, 11.7%). For plastic-protected films the range was from 0.96 to 1.22. Not included in these ranges are unusually low sensitivities caused by fogging and fading at ~97% humidity.

Miss Ehrlich concludes that bare film packets cannot be used for satisfactory personnel monitoring if there is prolonged exposure to relative humidities near 100%. At low temperatures high humidity causes latent-image fading; at high temperatures it causes emulsion fogging. (A more complete description will appear in *J. Research Nat. Bur. Standards* **65C**, No. 3, 1961.)

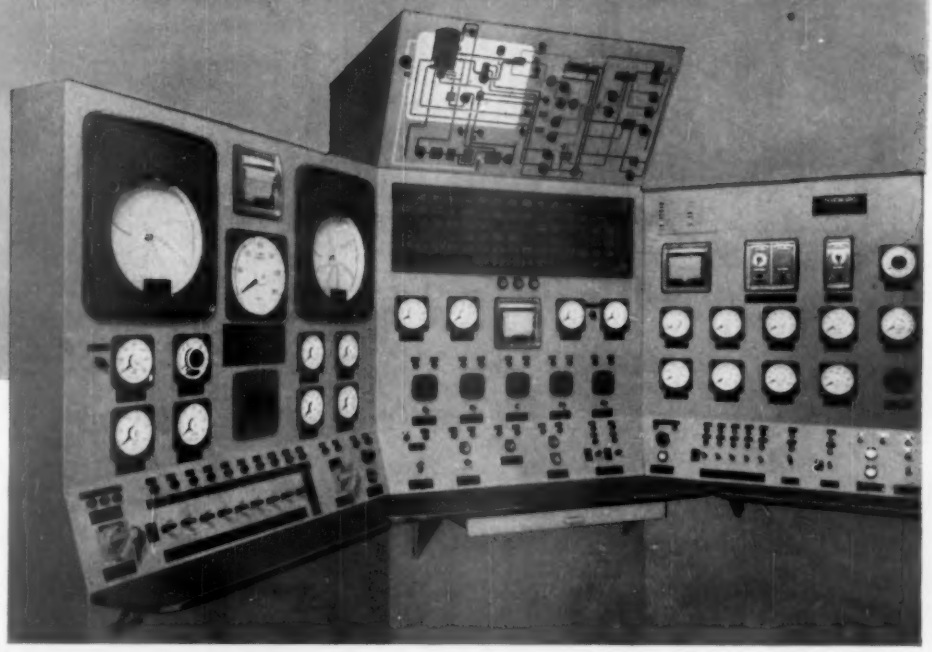
Wearable Air-Contamination Unit

To sample the atmosphere that a worker is actually breathing, the tiny device shown at right (arrows) sucks air at 1.5 liters/min through filter paper. Developed by Seymour Block, Edgar Beard and Arnold Forsman of Lawrence Radiation Laboratory, Livermore, it weighs only ¾ lb and runs for 9 hr on 26 ma from a rechargeable battery. Flow rate can be watched with a rotameter and controlled with a potentiometer. In 8 hr the device collects easily recognizable samples of plutonium (by alpha counting) or beryllium (by fluorimetric or spectrographic techniques) from maximum-permissible-concentration atmospheres.

Guaranteed motor life is 1,000 hr, but most motors last for 2,000.

for Arctic nuclear power plant . . .

Foxboro electronic Consotrols to operate 24 feet under ice!



Instruments on Foxboro-designed Console indicate, record and control reactor temperatures, flow, steam generator level, pressures, conductivity, as well as computing Btu's. Pressurized-water type reactor was designed and built by Alco Products, Inc., Schenectady, N. Y., for the U. S. Army Corps of Engineers.

Snow-Millers are cutting tunnels to connect various facilities of Camp Century. Under-ice equipment will be fully protected from Arctic environment.

24 ft. deep tunnels are covered permanently with metal strips. Powdered snow, blown back over them, forms roof of tunnel.

Instrument reliability a must at this Army base in Greenland

A complete community, buried 24 ft. under the ice — this is the U. S. Army's Camp Century, now under construction on the Greenland icecap, 800 miles from the North Pole.

The Foxboro-instrumented nuclear power plant — built on 10 separate skids — will provide power for the remote base. Its core of uranium will produce a year's supply of steam and electricity before refueling.

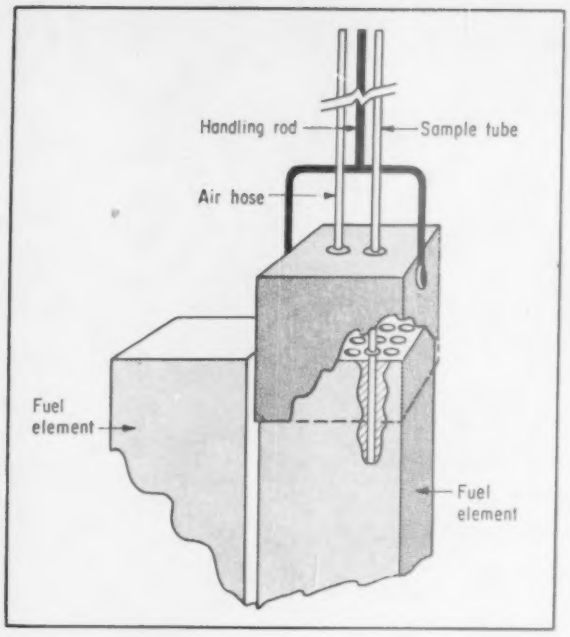
For this installation, where reliability is so critical, dependable Foxboro electronic Consotrol* instruments were specified. 100% solid state — no vacuum tubes to replace — instantaneous response. Instruments have been performance-proved to operate down to —20F, and to withstand storage temperatures as low as — 50F. Foxboro console can be easily operated by one man.

Foxboro electronic Consotrol instruments are especially suited for nuclear power control systems. Ask your Foxboro Field Engineer to show you the reasons why. Or write for Bulletin 1-17A. The Foxboro Company, 627 Neponset Avenue, Foxboro, Massachusetts.

Reg. U.S. Pat. Off.

FOXBORO

REG. U.S. PAT. OFF.



CHANNEL-PLUGGING DEVICE for VBWR is lowered with handling rod over top of fuel element. Air hose and tube for taking water samples penetrate box

Locating Failed Fuel in Water Reactors

by ROBERT N. OSBORNE
Vallecitos Atomic Laboratory
General Electric Co., Pleasanton, California

We have developed a method of locating failed fuel elements in water-cooled reactors by measuring the relative amounts of Te^{132} surface activity through its I^{132} daughter. The method is used during reactor shutdown and hence is quite useful for reactors such as Vallecitos Boiling Water Reactor that are not large enough to have elaborate built-in failed-fuel location systems. It also can provide a confirmatory check for failed fuel in large reactors containing such built-in systems. The technique has successfully located defective elements containing either uranium oxide or uranium-metal alloy.

The program to test experimental oxide fuel in VBWR included specimens with intentional defects and hence presented an ideal opportunity for developing methods for locating failed elements. Early in the fuel-test program we noticed that when a recently irradiated defective fuel element was transferred to the storage pool the iodine level of the pool water increased. Our first attempt to use this effect for locating failed elements involved the analysis of water samples taken from the individual fuel bundles while in their core positions. Although each fuel bundle is enclosed in its own channel, one trial showed that the iodine released from the defected fuel was distributed throughout the core by both convection and forced circulation reducing the signal-to-background ratio to an unuseable level.

Isolation can. The next approach was to isolate the fuel bundle and its coolant completely in an aluminum can suspended in the storage pool. The cans were 20-ft lengths of 5-in. id aluminum pipe sealed at one end. After insertion of the fuel, the open end of the can was raised above the water level of the storage pool to give complete isolation and at the same time continued cooling of the element. Samples of water were taken within 1 to 48 hr later from both the can and the storage pool and the specific activity of I^{131} measured. (The activity of the storage pool defined the background.) Four oxide fuel elements with known defects tested by this method gave signal-to-background ratios ranging from 50 to 1,000 depending on the type of defect and time of sampling.

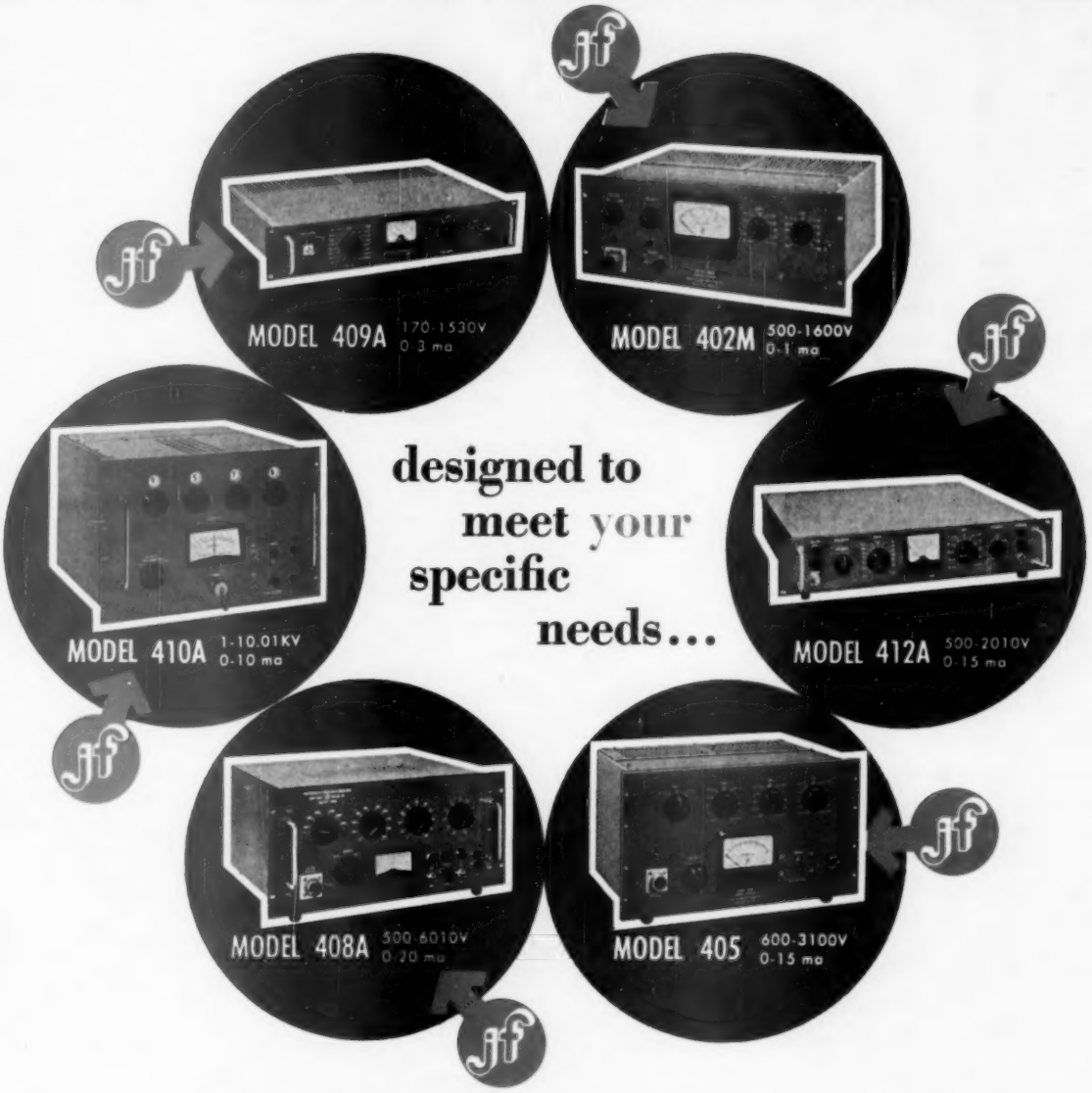
Following this successful demonstration of the can method with known defected elements an opportunity arose to test its efficiency in locating an unidentified defect. During tests of both defected and sound experimental oxide-fuel segments, one of the experimental segments ruptured. The rupture was signaled by an increase in fission-gas and iodine activity.

Our first step was to remove all the known defected fuel from the core. When operation resumed at power the continued high fission-gas and iodine release indicated that the defective element was still in the core. Next, to find the general core location of this unknown defect, we carried out a planned sequence of flux tiltings. By noting the rate of fission-gas evolution when different sections of the core were reduced in power we focused suspicion on a group of five experimental fuel bundles. These five elements were placed in individual cans in the storage pool three days after irradiation and analyzed for I^{131}.

Four of the five bundles showed roughly (within a factor of four) the same activity for measurements taken at one hour after isolation with no change in activity fourteen hours later. The fifth bundle displayed an activity 27 times the lowest reading of the other four bundles at one hour and 1,200 times the lowest reading fourteen hours later. Subsequent examination showed one segment had failed in this bundle. The increase in I^{131} specific activity with time in the can containing the defective fuel, contrasted with the constant readings for sound fuel, can be used for a confirmation of defect.

Channel plug. Although the can method has proved effective, its use at VBWR is complicated by the physical separation of reactor vessel and storage pool. Fuel transfers took considerable time and were subject to the possibility that defective fuel might occasionally release substantial amounts of iodine while in the dry fuel-handling cask. An obvious improvement would be a method to completely isolate an element in its core position. So far we have not worked out a scheme to do this. But we have devised a

HIGH VOLTAGE POWER SUPPLIES



designed to meet your specific needs...

JOHN FLUKE precision High Voltage Power Supplies offer complete coverage up to 10 KV. In addition to high calibration accuracy, tight line-load regulation, fine voltage resolution, and excellent long term stability; many other plus features are provided the design engineer. For example: difficulties resulting from corona, jitter, bounce or overshoot are non-existent in jf supplies. The capability of the John Fluke Co. to keep pace with industry demand is evidenced by the fact that most of these instruments have been introduced within the past year.

MODEL	VOLTAGE	CURRENT	REGULATION		STABILITY PER HOUR	MAX. RIPPLE RMS	RESOLUTION	PRICE
			LINE	LOAD				
409A	170-1530V	0-3 ma	0.01%	0.4%	0.02% (Per Day)	0.002%	85V steps	$335.00
402M	500-1600V	0-1 ma	0.03%	0.03%	0.01%	5mv	100mv	$320.00
412A	500-2010V	0-15 ma	0.01%	0.01%	0.005%	5mv	10mv	$455.00
405	600-3100V	0-15 ma	0.01%	0.005%	0.005%	5mv	10mv	$595.00
408A	500-6010V	0-20 ma	0.01%	0.01%	0.005%	5mv	10mv	$695.00
410A	1000-10,010V	0-10 ma	0.01%	0.01%	0.005%	5mv	10mv	$1095.00

All prices quoted, F.O.B., Factory, Seattle. Prices and technical data subject to change without notice.

Designed to power photomultiplier tubes and ionization chambers . . . for research and development of traveling wave tubes and backward wave oscillators.

FLUKE

JOHN FLUKE MFG. CO., INC.
P. O. Box 7428 Seattle 33, Washington

The premium thermocouple wire with metal sheath and mineral insulation (.020" to .500" O.D.) for universal application especially when high temperatures, high pressures, or space limitations are factors, and for sensitivity and quick response.

Many sizes in I.S.A. calibrations with 304 stainless steel or Inconel sheath and MgO insulation carried in stock. Hundreds of other combinations may be ordered to suit conditions.

Get the facts on XACTPAK today
BULLETIN 1-500
Thermocouples
Fittings
Connections
Terminations
and Assemblies

CLAUD S. GORDON CO.

Manufacturers • Engineers • Distributors

619 West 30th Street, Chicago 16, Ill.
2015 Hamilton Ave., Cleveland 14, Ohio

system that plugs the coolant flow from the top of a fuel channel, converting the channel into an inverted can. The device (see figure) consists of a box slightly larger than the channel that slips over the top of the element between the channel and the holddown grid. Air is then forced into the box and the top of the fuel channel to form a pocket that plugs the flow of coolant from the top of the channel. The box also contains a sample tube through which coolant can be removed from the channel.

The VBWR schedule allowed only one run with the channel-plugging apparatus before it was shut down for the high-power-density modification. The element tested contained a small known defect. Under irradiation this element released fission products equivalent to the background tramp uranium level of the core (or that from ~3 mg of U^{235}). Two tests of the device were carried out. We first measured the response of the channel-plugging method to the small defect 20 hr after reactor shutdown and then repeated the measurement 31 hr later.

Test No. 1
(20 hr after irradiation)

Plugging time (min)	*I^{131} activity ratio (defect fuel/sound fuel)*
10	3.9
30	4.8

Test No. 2
(51 hr after irradiation, 10 min plugging time)

Isotope	*Activity ratio (defect fuel/sound fuel)*
8-day I^{131}	11
21-hr I^{133}	13
2.3-hr I^{132}	≥200

These tests led to the following conclusions:

- The plugging method will give a signal-to-background ratio of ≥4 for a small defect. If the signal is proportional to the magnitude of the defect, a defect large enough to interfere with reactor operation will yield a signal-to-background ration of ~100.
- A 10-min plugging time appears sufficient.
- The Test-2 data show that the signal persists and in fact increases with time.
- The signal-to-background ratio for I^{132} is ≥200. This most interesting result had not been noted in previous runs because the time delay between sampling and counting had allowed the I^{132} to decay.

Because the fuel had cooled for 51 hr, the source of the 2.3-hr I^{132} signal could only be its 77-hr Te parent. We have known* that oxide fuel releases Te^{132}, which, once it is released, deposits entirely on the system surfaces. The result of this test suggests that the Te^{132} is primarily deposited in the *immediate vicinity of the defect*. Future runs with either channel-plugging or the can method should be directed towards measuring the signal-to-background ratio of I^{132} instead of that of I^{131} or I^{133}.

Based on the success of the one run with a channel plugging device in VBWR a similar but somewhat more elaborate apparatus was built for the Dresden Nuclear Power Station. Dresden already contains a built-in failed-fuel location system which functions during power operation; however, the channel plugging device was added to confirm the predictions of the built-in system. The device remains to be field tested.

GETR defects. Following the shutdown of the VBWR, fuel defects found in the GE Test Reactor at Vallecitos provided two opportunities

* NU, Dec. '57, p. 54 and J. D. Eichenberg, Effects of irradiation on bulk UO_2, WAPD-183.

GETR Fuel-Element Activity Levels

Group / *Element*	*I*	*II*	*III*	*IV*	*V*	*VI*
			I^{132} relative values			
A	1.1	1.0	1.3	5.2	1.0	2.6
B	1.0	1.1	1.1	4.2	2.3	1.0
C	1.5	1.3	1.3	4.7	1.2	
D	7.6	1.4	1.0	1.0	3.5	
E	250	2.1	1.0	1.9	2.5	

EX-CELL-ABILITY...

. . . is quality control. It is laboratory analysis of raw materials and heat processed parts. It is experience in the design, production, and application of our own gages, optical contour projectors and other inspection equipment. Ex-Cell-Ability is the guarded quality built into every Ex-Cell-O Atomics product, whether control rod drives, remote handling equipment or precision parts and assemblies. Write for details, or phone TOwnsend 8-3900; TWX DE-175; cable XLO.

EX-CELL-O CORPORATION
DETROIT 32, MICHIGAN

Ex-Cell-O Atomics — EX-CELL-O FOR PRECISION (XLO)

61-68A

A MAJOR ADVANCEMENT IN
CERMET FABRICATION TECHNOLOGY

COATED PARTICLES & PARTS BY

NUMEC®

COMMERCIALLY AVAILABLE FROM NUMEC—A LARGE NUMBER OF METALLIC AND NON-METALLIC coatings on base materials.

TYPICAL COATING MATERIALS— Cu • Ni • Cr • Nb • V • Mo • Si • Be • W • C (pyrolytic) • BeO • SiO_2 • Al_2O_3 • (Duplex coatings also available)

TYPICAL BASE MATERIALS— UO_2 • UC • U metal • ThO_2 • WC • BeO • SiO_2 • C • glass • steels • alloys • semi-conductors • carbides • refractory metals • graphite •

NUMEC coatings can be applied to base materials including fine powders, spheres, pellets, tubing, plates, sheet, and other more complex configurations. For information on coated particles, nuclear materials or special service contact:

NUMEC
Nuclear Materials & Equipment Corporation
Apollo, Pa.

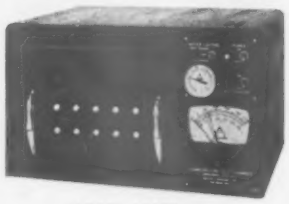
Phone: GRover 2-8411

Cable: NUMEC TWX: APO-276

NUMEC's growth is constantly creating new and challenging opportunities for scientists and engineers in basis research and development. Write today for information.

+500°F TO -100°F
in SIX minutes

With NEW DELTA TEMPERATURE CHAMBER

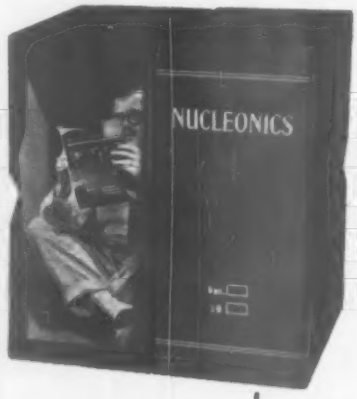


MODEL 1060F

Rapid temperature cycling without sacrificing precise control (± ½ ° F) is achieved with the Delta 1060F temperature chamber.
This convenient bench model can make the complete cycle between —100° F and +500° F in less than twelve minutes.
An auxiliary timer Delta MR-1 is available for use in test work where automatic cycling is desired.
For further information on the 1060F and other Delta temperature chambers, contact your local Delta representative or write

DELTA DESIGN INC.

3163 Adams Ave.
San Diego 16, Calif.
ATwater 3-3193
TWX: SD 6488U
Cable: DELTA



a magazine file for NUCLEONICS readers

ORDER NOW

price: $2.50 each
3 for $7.00,
6 for $13.00

- Each file holds a full year's copies.
- Covered in durable, leather-like Kivar, title embossed in 16 kt. gold.

We pay all postage charges in the U.S.A. Canada and Foreign add $1.00 per order. SATISFACTION GUARANTEED OR YOUR MONEY BACK.

Order direct from:
MAGAZINE FILE COMPANY
520 FIFTH AVENUE
NEW YORK 36, NEW YORK

FREE DESCRIPTIVE FOLDER UPON REQUEST

This article starts on page 84

to measure the efficiency of the can method for locating defective uranium-alloy fuel. (The GETR is a low-temperature, pressurized test reactor, containing 26 flat-plate U-Al alloy fuel elements.)

The can method was used at the GETR in preference to channel plugging for two reasons. The reactor vessel and storage pool are connected by a canal so that fuel transfer is easily done. Secondly, the signal obtained is more definitive than one derived from partial isolation by channel plugging.

On the first occasion, following the indication of defective fuel in the GETR, five suspect elements were placed in aluminum cans 24 hr after irradiation. I^{131} and I^{133} levels measured at both 33 and 58 hr after irradiation easily identified the failed element. The I^{131} signal-to-background ratio for the metal fuel was a third larger at 33 hr and four times larger at 58 hr than that of the I^{133}. However, the I^{133} photopeaks interfere with the early measurement of I^{131} so that the time lost in the analysis of I^{131} does not compensate for the gain in signals.

Following the second indication of defective fuel in the GETR, a scheduled outage presented an opportunity to examine all 26 elements to determine the extent to which Te^{132} is distributed. The number of isolation cans limited the measurements to groups of five. In the results shown in the table all values are normalized to the lowest iodine level in each group.

Examination of element I-E showed defective cladding. The fuel in Group IV was placed in the cans only 2 hr before sampling while the remaining groups had been in cans from 6 to 8 hr. The erratic results in Group IV suggest that longer delays will yield better results. Except for element I-D (which was in the adjacent core position to the defective element I-E) and the elements in Group IV, the Te^{132} appears to be evenly distributed throughout the core.

* * *

The author wishes to acknowledge the valuable assistance given by the operating crews of both the VBWR and GETR in performing the many fuel movements. The assistance of K. Stratton in the design and operation of the VBWR channel plugging device and C. D. Carroll who designed the Dresden channel plugging device is also acknowledged.

High Pressure-
High Temperature
Equipment*

COMPACT
LIGHTWEIGHT
EASY TO INSTALL

AUTOCLAVE ENGINEERS ERIE, PA.

SPACESAVER
Stainless Steel Valves

Here is a stainless steel tubing valve—precision made yet rugged—which gives you improved performance *plus* savings in space, time and money. The SpaceSaver is more compact and lighter in weight than any other valve of comparable tubing size and pressure rating. Although capable of handling gases and liquids at 12,000 p.s.i., these valves are priced for practical use at all lower pressures. Full port openings—with minimum pressure drop through the valve—are a major advantage. And installation is quick and easy—no threading, swaging, flaring, welding or special tools are required.

AE SpaceSaver Valves are of 316 s.s. construction and are available for ⅛" O.D., ¼" O.D., ⅜" O.D. or ½" O.D. tubing.

Bulletin 257 gives complete information—yours for the asking.

AUTOCLAVE ENGINEERS, INC.

2934 West 22nd Street • Erie, Pa.

* Designers and Builders of High Pressure-High Temperature Equipment including: Valves • Fittings • Stirred Autoclaves • Reactors • Pumps • Compressors • Complete High Pressure Package Systems including Instrumentation and Controls.

BONUS Superheat Reactor Off to Good Start

One of the two superheater central station power reactors under construction by the U. S., the BONUS (BOiling NUclear Superheat) Reactor is about 22% through its construction schedule (see Fig. 1). Criticality is expected in December of 1962. So far construction is on or ahead of time and costs are also holding to plan. When completed at its Punta Higuera site (on the westernmost tip of Puerto Rico), the 17.3-Mw(e) power plant will operate under joint ownership—the nuclear part of the plant will be the property of the U. S. AEC and the generating part that of the Puerto Rico Water Resources Authority. The latter also designed the generating part of the plant while General Nuclear Engineering Corp. designed the nuclear part.

The reactor core (see Fig. 2) consists of two regions: a central boiling region with zircaloy-2 UO_2 fuel and a peripheral superheating region with stainless-steel-clad UO_2 fuel. Nine cruciform control rods are located entirely within the boiling region, and an additional eight slab-type rods are located between the two regions. Control rods are of boron-stainless-steel alloy.

The reactor operates at a power level of 50 Mw(th) to provide 17.3 Mw(e) with the boiler region generating 37 Mw(th), and the superheater region generating the remaining 13 Mw(th). Steam flow at the turbine throttle is 152,000 lb/hr at a pressure of 850 psig and a temperature of 900°F. The condensate returns at 354°F through four stages of feedwater heating. Two recirculation pumps in separate loops provide forced-circulation cooling water to the boiling region.

The cruciform rods in the boiler region are adjusted together with the slab rods to accomplish desired changes in total power output without altering the relative outputs of the boiler and superheater regions.

The superheater was located at the outer core periphery (in a region of comparatively low power density) to match heat removal capabilities of boiler and superheater with the expected radial drop off in power. (Superheater power density is lower than boiler power density because of comparatively poor heat-transfer properties of steam and relatively low heat-transfer surface-to-core-volume ratio of the fuel-element configuration.) Also competing effects of core-neutron leakage at the core periphery minimize the reactivity changes caused by flooding or voiding of superheater elements. If the superheater were at the center of the core, there would be a substantial positive reactivity gain upon removal of water from the coolant channels. In addition location of the superheater on the outside of the core, in the high neutron leakage zone, yields a higher over-all conversion ratio than at the core center.

On leaving the boiler assemblies, the steam-water mixture at the core exit flows upward through steam-separation equipment; dry steam then flows back down to the superheating fuel assemblies. The steam makes four heating passes through the superheater and returns to the steam dome, which connects to the turbine inlet.

Saturated-steam inlets to the superheater are located near the uppermost point in the reactor steam dome to take advantage of the natural gravitational steam-water separation in this region. Most of the remaining small droplets of moisture are removed by four mechanical steam dryers located at the inlets.

Maintaining coolant steam flow in the superheater at all times is an important safety problem. The main condenser and the emergency condenser are used as heat sinks. Upon stoppage of steam flow to the turbine or upon power failure, valves automatically open in bypass lines leading to one or both of these heat sinks, thereby assuring an adequate supply of steam to prevent damage to the superheater fuel.

The superheater zone will be instrumented to obtain data from individual elements and could serve as a test bed for new types of superheater elements. However most of the time the plant will be on base-load duty on the Water Resources Authority's grid.

FIG. 1. PALM TREES AND OCEAN SURF form pleasant backdrop for BONUS Reactor on Puerto Rico seacoast. "Total containment" shell will house entire station including turbogenerator

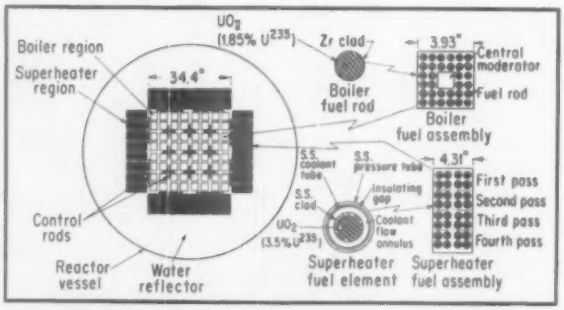


FIG. 2. BONUS CORE consists of 8 × 8 array of boiling fuel assemblies surrounded by four banks of superheater assemblies. Control rods regulate power sharing between two regions

MIDWEST NUCLEAR FITTINGS GO TO SEA IN OUR ATOM-POWERED FIGHTING FLEET

Midwest nuclear fittings have grown up with America's atomic-powered navy development program. They were used in the prototype of the submarine Nautilus, first-born of the nuclear fleet. Today, they're cruising on or beneath the seas in such vessels as the cruiser Long Beach, first nuclear-powered surface ship, the aircraft carrier Enterprise, the destroyer Bainbridge and a host of atomic submarines.

Fittings for these seagoing nuclear power plants were formed from stainless steel, stainless clad steel and Inconel, under rigid quality control and to the extremely stringent specifications for marine reactor piping.

In addition to these special fittings, Midwest produces a complete line of stock fittings and flanges, in carbon steel and alloys, for marine use.

Write today for Midwest Bulletin 60-A, "Critical Piping for the Nuclear Age," describing Midwest's manufacturing, fabrication and erection facilities. The 20-page booklet includes numerous examples of nuclear installations in which Midwest products and services were used.

6139

MIDWEST PIPING

A DIVISION OF CRANE CO.
1450 S. SECOND STREET
ST. LOUIS 4, MISSOURI

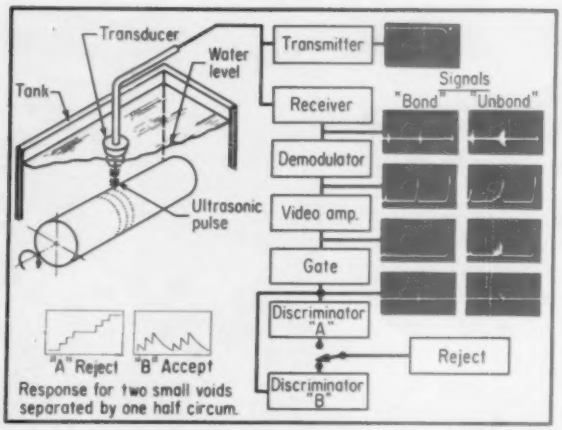


FIG. 1. ULTRASONIC TEST scans Al-clad slug for unbonded regions. 20-Mc pulses are 0.5 μsec long with 3,400 pulses/sec

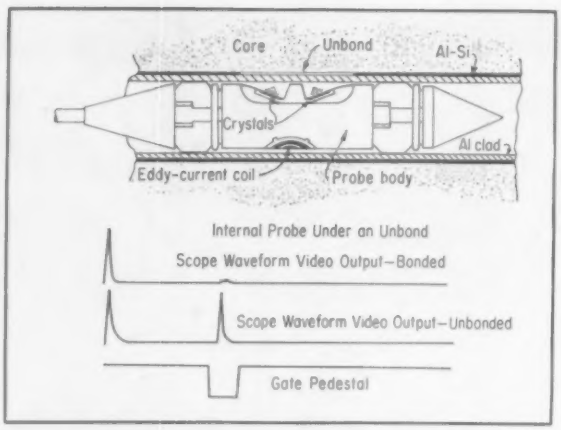


FIG. 2. LAMB-WAVE-TEST crystal pair scans bore cladding for unbonds. Eddy-current coil checks for penetration defects

Inspecting Fuel-Slug Cladding at Hanford Automatically

by DANIEL C. WORLTON, *Hanford Atomic Products Operation, General Electric Co., Richland, Washington*

The cladding of Hanford process fuel must be well bonded to the uranium core to provide adequate heat transfer and it must be free of defects or thin spots which would lead to corrosion failure for the expected in-reactor residence time. Automatic eddy-current and ultrasonic test stations assure that these requirements are met through inspections simultaneously applied to the external and internal cladding surfaces of the hollow tubular Hanford elements. [An article last month (NU, June '61, p. 80) described the tests performed on the fuel slugs themselves.]

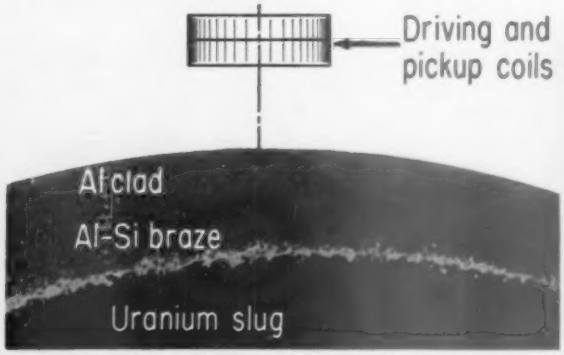
The ultrasonic test measures the area of each unbond defect. It may be set to reject defect areas as small as 0.001 in.[2] The eddy-current test rejects cladding defects that reduce the effective can-wall thickness below a preselected minimum. Present equipment enables the rejection level to be set at any can-wall thickness up to about 0.025 inches.

External Bond Test

Hanford fuel is fabricated with a lead dip process in which the fuel cores are preheated in a lead bath and canned in 45-mil-thick aluminum cans with an aluminum silicon bonding alloy whose thickness averages 0.010 in. Possible bonding layer defects are

- Voids—characterized by gas pockets frozen into the AlSi
- Non-wets—where the AlSi fails to properly wet the aluminum can
- Brittle bonds—where either a fracture exists at the AlSi-U interface or the bond is mechanically weak

The pulse-echo ultrasonic equipment shown in Fig. 1 readily detects voids, non-wets and fractured brittle bonds. As it travels past the test head the fuel rod rotates at about 960 rpm, advancing $\frac{1}{16}$ in. per revolution. When the 20-Mc ultrasonic pulses impinge upon the surface, reverberations build up in the can wall directly over unbonded regions. These reverberations have characteristic frequencies that depend upon the depth of the unbond; their decay with time lengthens the time



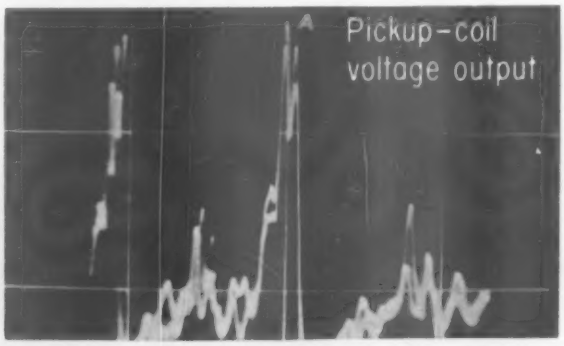


FIG. 3. EDDY-CURRENT TEST for cladding thickness. Driving coil excites local eddy currents in cladding. Pickup-coil signal (right) reflects changes in eddy-current strength caused by variations in thickness of aluminum cladding

FROM MID-CHANNEL: "I'm A-O.K., Jack!"

Captain Boyton, in his new floating costume, fully proved, in 1875, the utility and value of his invention. It was no mean triumph to have sustained 15 hours battling the stormy seas, accomplishing 50 miles in distance.

We at NUCLEONICS are now in "mid-channel" in our preparations for our September Nuclear Navy report, and can safely report "we're A-O.K.," too. As in 1959, for our award-winning* report, "Building the Nuclear Navy," we have begun to collect and assemble data. The complete story of the conversion of the U. S. Navy to nuclear propulsion—including the table listing all nuclear-propelled Navy ships, their characteristics and major suppliers—will be updated for this issue. The tempo of the conversion to nuclear propulsion is accelerating — 61 nuclear ships are already at sea, under construction, or on order. The report will contain all the latest policy thinking and facts about the Nuclear Navy program.

The September issue will be a porthole through which our readers will view the Nuclear Navy program and the multi-billion dollar market which it represents. The 61 nuclear ships involve expenditures of $4.2-billion to date. In addition, 10 more Polaris subs and two new surface ships are in process of being approved by Congress at this moment—part of the Navy's long-range goal of making all combat ships nuclear propelled. Present and potential suppliers to the Nuclear Navy must continue to keep the buying influences aware of their companies and their capabilities.

We suggest that advertisers plan *now* to "come on board" our September issue and display their product to an audience of buying influence in a proven best-seller.

CLOSING DATES:

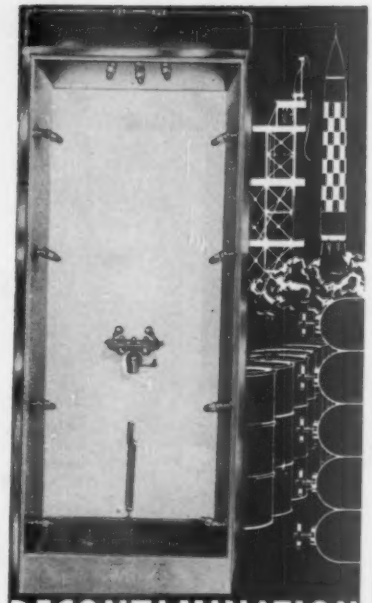
Space reservations and copy to be set.....July 24

Complete plates.....August 1

**The 1959 report, "Building the Nuclear Navy," received a Jesse H. Neal Editorial Achievement Award for outstanding journalism, as did our 1957 report, "Nuclear Navy Paces Atomic Industry." The reason for the two awards: imaginative and creative reporting, resulting in two Nuclear Navy packages comprised of information available nowhere else. As testimony to the interest in the Nuclear Navy,* NUCLEONICS *has sold over 6,600 reprints of these two reports.*

NUCLEONICS

A McGRAW-HILL PUBLICATION / 330 WEST 42ND STREET, NEW YORK 36, NEW YORK



DECONTAMINATION BOOTH

Instantly ready for vital FIRST AID

HAWS

Miscues and accidental exposure to dangerous propellants and other chemicals can occur with shocking suddenness. Adequate water irrigation is an important key to minimizing such injuries and subsequent claims. HAWS Decontamination Booth is the answer... a complete safety station for immediate first aid.

HAWS MODEL 8600 DECONTAMINATION BOOTH

is made of durable, lightweight reinforced fiberglass plastic, and features Haws Eye-Face Wash Fountain, eight lateral body sprays and overhead spray unit. **All are simultaneously activated by weight on the base-mounted foot treadle!** Contaminated victims are instantly "covered" with water that floats away foreign matter from body and clothing.

At aeronautical and astronautical installations everywhere, HAWS Safety Facilities are important in boosting air-age safety programs. Find out what this equipment can mean to your operation. Full details sent on request, with no obligation.

HAWS DRINKING FAUCET CO.

1441 FOURTH ST. • BERKELEY 10 • CALIFORNIA

EXPORT DEPARTMENT • 19 COLUMBUS STREET SAN FRANCISCO 11, CALIFORNIA

Inspecting Cladding

This article starts on page 92

duration of the pulse reflected from the surface. The reverberations are electronically isolated from normal surface reflections to reveal unbonded defects.

During the eight seconds the 8-in.-long fuel rod passes under the test head, the external surface is interrogated at a rate of 3,400 pulses per second. Thus, consecutive pulses strike the surface at points separated by about 0.02 in.

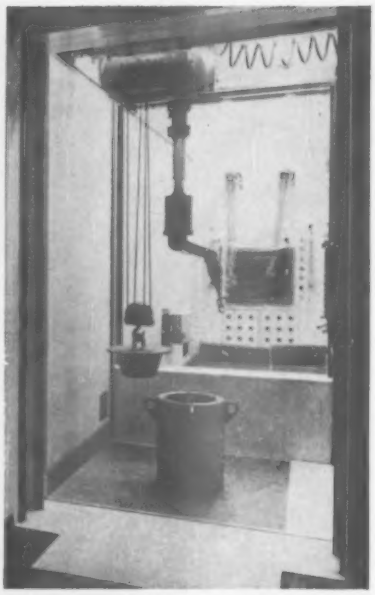
If we define an affirmative interrogation to mean a surface-reflected pulse whose time duration is extended with the characteristic reverberation pattern from an unbond defect, then a consecutive count of these is a measure of the transverse length of each unbond area. Circuits are included in the equipment to measure this dimension. Additional circuits measure the effective defect length in the axial direction. On the basis of these measurements the instrument can automatically segregate elements with unbond areas exceeding some maximum acceptable size. Also, because the ratio of total affirmative interrogations to total interrogations is a measure of total percentage of unbonded area, when desired discriminator "A" will segregate material according to a total percentage specification by simply summing the affirmative interrogations (see Fig. 1).

Internal Bond Test

Inspection of the internal cladding required special techniques. The pulse-echo method, while successful on the external surface, is not applicable to the bore because the small radius of curvature ($\sim\frac{3}{8}$ in. diam) so severely refracts the incident ultrasonic energy that reverberations cannot build up in the can wall.

We eventually solved the problem by employing relatively obscure ultrasonic waves known as Lamb waves. These waves (named after Horace Lamb who theoretically predicted their existence in 1916) are distinguished by the readiness with which they are excited in thin section.* For example, a section of unbonded cladding theoretically can support up to an infinite number of modes of vibration. Contrary to other ultrasonic waves whose velocities are fixed for a given metal, Lamb waves propagate with different velocities,

* D. C. Worlton. Lamb waves at ultrasonic frequencies, HW-60662 (June 9, 1959).



PHENOLINE COATINGS PROTECT VALLECITOS' HOT CELLS

➤ No sign of degradation after three years of radiation exposure

➤ Easy to wash down with ordinary detergent

Research conducted in the hot cells at Vallecitos Atomic Laboratory is benefiting many industries. At this General Electric facility near San Francisco, studies include experiments on the effects of radiation on metals, fuels and other materials, with a view to improving properties and performance.

Four years ago, the cells were coated inside and out with a three coat application of Phenoline 305, a slick-surface, modified phenolic-base material highly resistant to impact and degradation from radiation. For the past three years, interior surfaces have been routinely exposed to more than 1,000 Roentgens of radiation per hour.

To date, no deterioration in the protective coating is evident. No repainting has been needed.

Surfaces are washed down by remote control with an ordinary floor polisher and household detergent.

■ Write for detailed information on Carboline's Phenoline 305, the protective coating for concrete and steel, recommended for areas where maximum protection is demanded.

carboline COMPANY

Coatings with Nuclear Experience

32-P Hanley Industrial Ct.
St. Louis 17, Mo. 6103

BJ Pumps for all water-cooled Power Reactors...

Liner-Motor and controlled leakage!

12 of these *two-stage*, liner-motor pumps are being furnished for ultra high-pressure nuclear service.

The first large, two-stage pumps for high-pressure nuclear service are now being completed by Byron Jackson. Designed for differential heads up to 1600 feet, six of these pumps will be rated at 75 horsepower, and six at 275 horsepower.

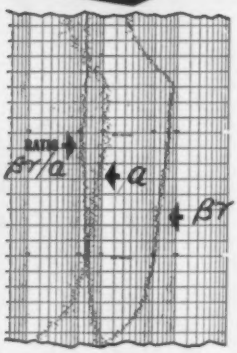
BJ is the only manufacturer who designs and builds all types of pumps—liner-motor, mechanically-sealed or controlled leakage—for all types of water-cooled power reactors.

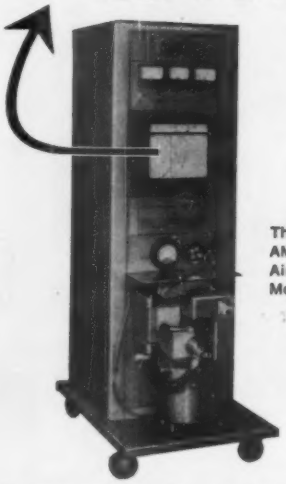
Whether portable, central station or for experimental test loops, BJ meets the special demands of high pressure, high temperature and radiation with a background of experience in nuclear pumps since 1944, and in quality pumps and products since 1872!

BYRON JACKSON PUMPS, INC.
SUBSIDIARY OF BORG-WARNER CORPORATION
P.O. Box 2017 Terminal Annex,
Los Angeles 54, California

BYRON B-W JACKSON
BORG-WARNER

This Air Monitor Solves the Natural Radon Progeny Problem





The New AM-33R Air Monitor

The AM-33R is First to Provide *Direct* Identification of Long Half-Life Emitters

Due to natural radon progeny, identification of long half-life emitters with ordinary monitors means a delay of five hours or more, and requires multiple detectors. Now, with the new AM-33R air monitor, the presence of these emitters can be identified directly, and almost immediately—with a single detector.

PRICES—FOB, INDIANAPOLIS

AM-33R (Moving Filter) Illustrated $6,580.00
AM-22R (Fixed Filter) $5,230.00

FOR DETAILS, PHONE LIBERTY 6-2415 COLLECT

NMC

Nuclear Measurements Corp.
2460 N. ARLINGTON AVE.
INDIANAPOLIS 18, INDIANA
International Office: 13 E. 40th St., New York 16, N. Y.

Inspecting Cladding

This article starts on page 92

depending upon the order of the mode, frequency and cladding thickness. The waves are experimentally excited by plane longitudinal ultrasonic waves striking the cladding surface at properly chosen angles of incidence. They are detected by a receiver transducer oriented to pick up energy radiated from the surface at an exit angle equal to the incident angle.

In well-bonded cladding only Lamb waves of greatly reduced amplitude are excited. Thus, an unbond defect is detected by a sharp increase in energy amplitude reaching the receiver transducer.

Figure 2 shows the internal probe used for this test. Either crystal serves as a send transducer and the other as a receiver. As the waves travel through an unbonded cladding, energy is radiated to the receiver crystal—a large amplitude pulse for an unbond defect and (with proper transducer design) practically no energy for a well-bonded interface.

Recent studies have revealed significant advantages for the Lamb-wave technique. The test can be applied to generator bonding-layer forces that stress the bond in either tension or shear. Shear forces readily reveal brittle, but unbroken, bonds. This type of defect is more difficult to detect with the pulse-echo method whose longitudinal waves stress the bond primarily in tension. Studies are evaluating the application of Lamb waves to the external as well as the internal surfaces. The inspection probe mounted diametrically opposite the Lamb-wave test head in Fig. 2 is an eddy-current coil that inspects the integrity and thickness of the cladding.

Penetration Test

Improper canning-process variables may cause the AlSi braze compound to excessively erode the inner surface of the aluminum cladding in localized regions. These penetration defects create thin spots in the cladding and greatly enhance the risk that the braze might be exposed to the coolant after a period of corrosion in the reactor.

The same tests serve to detect penetration defects in both external and internal claddings. In each instance two small coils of wire are mounted together as a transformer and positioned near the cladding surface. With the primary winding driven at 20 kc, eddy

THERMOCOUPLE WELLS

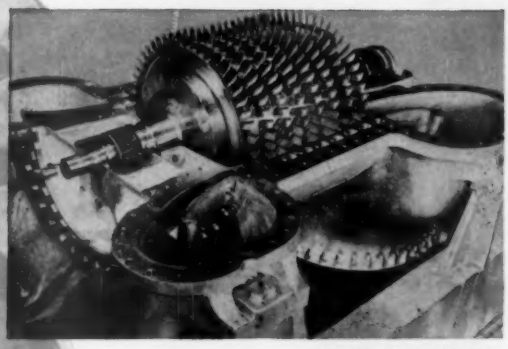
Nine basic types of standard pressure-tight wells, with or without T/C assemblies, and any type of special wells made to order. All are beta-gage checked for concentricity. Thermocouple wells are among thousands of accessories—all available from a single dependable source—that can help your instruments perform at their very best.

Get complete details from your nearby Honeywell field engineer, or write today for Catalog G100-5.

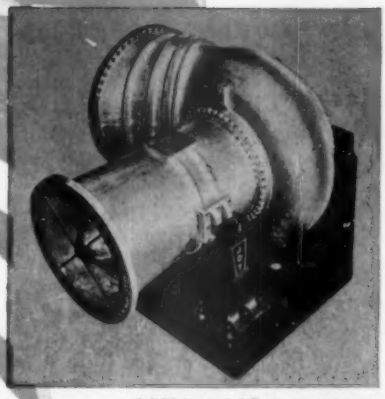
MINNEAPOLIS-HONEYWELL, Wayne and Windrim Avenues, Philadelphia 44, Pa. In Canada, Honeywell Controls, Ltd., Toronto 17, Ontario.

Honeywell
First in Control
SINCE 1906

Assembly of Barrel Compressor.



15,000 hp multi-stage axial flow compressor.



6,000 hp axial flow compressor with 1100°F inlet temperature.

JOY OFFERS UNIQUE CAPABILITIES IN GAS CIRCULATOR DESIGN

Compressing gases at the high temperatures and pressures required for gas-cooled reactor loops is routine to Joy engineers. In working with the nuclear power industry, Joy has provided compressors capable of handling inlet temperatures to 1100° F, considerably above design temperatures now used in primary loops. Double-case construction and metallurgical design know-how have solved the many difficult structural and thermal problems.

Full consideration has been given to the problems relating to controls and aerodynamic stability of reactor cooling loops using circulators in parallel. A unique line of centrifugal compressors has been developed with extremely desirable characteristics. Increasing pressure with decreasing volume is available to zero flow, with no flow instability or surge.

In addition, Joy is the exclusive distributor in the United States for De Havilland Gas Circulators for radioactive auxiliary and test circuits. These circulators are leak-proof and contamination-free. An outstanding feature of their design is the use of gas bearings.

For complete details on Joy gas circulating compressors, write for Bulletin 1282-92.

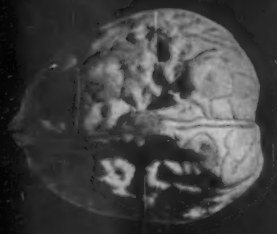
AIR MOVING EQUIPMENT FOR ALL INDUSTRY

JOY

Joy Manufacturing Company
Oliver Building, Pittsburgh 22, Pa.

In Canada: Joy Manufacturing Company (Canada) Limited, Galt, Ontario

a vacuum pump as compact as a . . .



Yes, designed for compactness . . . and with no costly extras to buy. Saves up to 50% of your valuable floor space. But these are just a few of the revolutionary features of the new Stokes Series H Microvac pump.

Find out why Stokes offers you *more pumping performance per dollar*. Just write: Vacuum Equipment Division, F. J. STOKES CORPORATION, 5500 TABOR RD., PHILA. 20, PA.

STOKES

SEND TODAY
for your free
Vacuum Slide Calculator!

Inspecting Cladding

This article starts on page 92

currents induced in the cladding affect the voltages generated in the secondary winding. The amplitude and phase of the secondary voltage are related to the electrical conductivity of the cladding near the coil.

Figure 3 illustrates the application of this technique to the external surface. Since the conductivity of AlSi is about two-thirds that of aluminum, AlSi penetrations into the cladding wall change the secondary voltages. These small signal variations are amplified and measured with respect to amplitude and phase.

However, these signals are also extremely sensitive to probe-to-surface spacing so it is necessary to select signal components that discriminate between this effect and bonafide penetrations. Small variations in spacing can be compensated to a degree by phase detector or center-of-curvature amplitude detector schemes; but at high testing rates it is virtually impossible to keep these variations within limits for which straightforward electronic techniques can compensate. The most successful method of mechanically compensating for these variations places the external test coil on the element surface (with a teflon tape between them to take the wear). A clock motor slowly pulls the tape past the test head to keep it from wearing through.

Spacing variations are minimized on the inside test by bearings mounted on either end of the probe assembly to keep the probe centrally aligned in the bore.

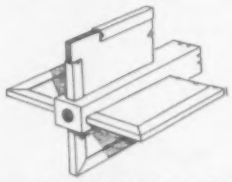
Experience shows that the equipment reliably segregates penetrations in the aluminum that reduces the effective can-wall thickness below any preselected value less than 0.025 in. Figure 3 pictures a typical penetration of the external cladding with wave traces indicating the signals with which it was detected.

Both the ultrasonic and eddy-current tests at Hanford are combined into a single test station. The elements roll to the station on skate-wheel conveyors, are automatically submerged into the testing tank, and move past the external and internal test heads. Rejects are automatically segregated according to bond or penetration rejects, while the accepts are placed on a continuing conveyor for delivery to the next fabrication step.

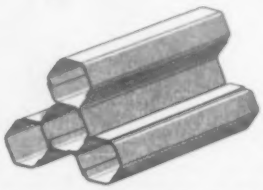
an effective material for neutron shielding

Boral is a uniform dispersion of boron carbide crystals in aluminum. Its high boron carbide content (up to 50%) enables it to absorb thermal neutrons without the production of hard gamma rays.

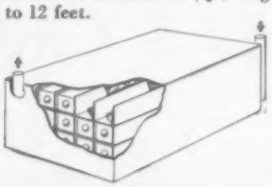
Boral Plate can be worked to meet the requirements of a wide range of shielding applications. It can be drilled, tapped, punched, sawed, sheared, formed, and welded. The accompanying sketches show typical designs and assembly methods.



Shut-down Control Rod for Reactors
Assembly of this unit is made by arc welding. All edges of Boral Plate are clad. The center bar is tapped to receive the threaded rod.



Storage Cells for Fresh Fuel
Cells are usually used in assemblies of several fuel units, encased in aluminum or stainless steel cylinders. The Boral shapes should have corner radii of ¾"; length can be up to 12 feet.

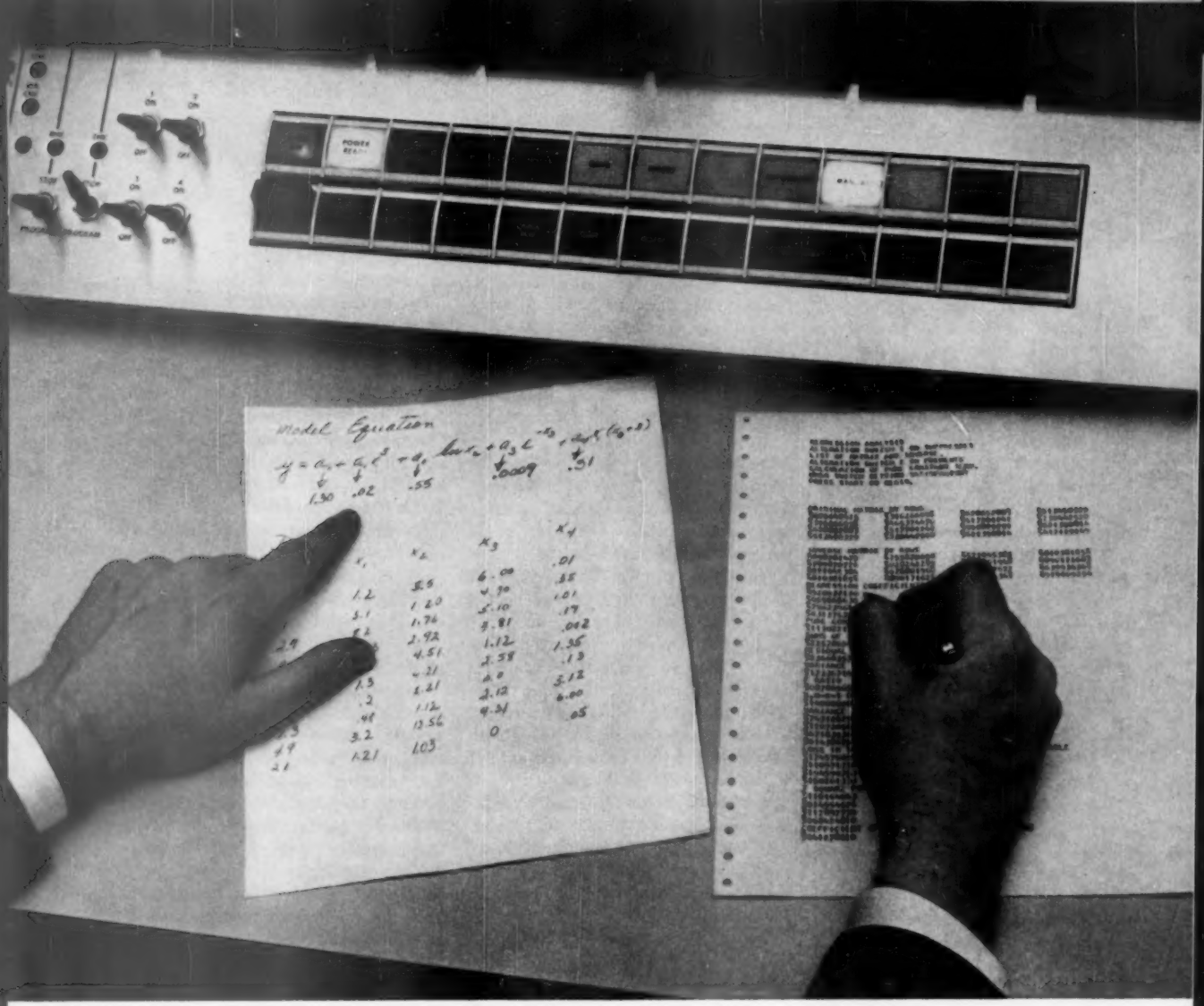


Water-cooled Boral-lined Case for Spent Fuel Elements
This Boral-lined aluminum case with egg-crate type separators for the transportation and storage of spent fuel units, is assembled from Boral Plate by arc welding.

Typical and Potential Applications
Reactor shields, neutron curtains, shutters for thermal curtains, safety rods, storage and shipping containers for fissionable material, fabricated boxes for radiation-sensitive devices, protective shields for easily activated components.

Brooks & Perkins, the first commercial producer of Boral, invites you to send for technical data and literature. 60-T-11

BROOKS & PERKINS, INC.
1926 W. FORT STREET • DETROIT 16, MICHIGAN
Offices in Washington and New York



Want to find the coefficients? It's easy with the new Regression Analysis program for the IBM 1620

Here's another program offered free-of-charge to users of the IBM 1620 Data Processing System. It gives you the kind of results you might expect only from a much more expensive computer. But users of the 1620 know that its low rental cost is deceptive. The 1620 packs *more computing power per cubic inch* than any other computer in its size range.

The Regression Analysis program is a good example. Suppose you want a fit for production purposes. If you employ more than two variables you probably have difficulty visualizing the representation of your data. If linearity is not the case, you must often guess blindly at a polynomial of high degree, accept or reject the fit with something approaching a sixth sense, and either try again or settle for the results you have.

The new Regression Analysis program lets you handle expressions containing up to 24 *variables*. If you have the even more complicated task of handling many dependent variables, the program will generate regression coefficients with a maximum number of dependent variables not exceeding one-half the number of independent variables.

This program will also fit non-linear functions and hyper-surfaces. Compare this performance with that of any other computer in the 1620's price range.

A basic 1620 installation rents for just $1600 per month. For details, contact your local IBM Representative.

IBM's 1620 is a compact desk-size computer.

IBM®
DATA PROCESSING

New Techniques Improve Detection of Tritium

Tritium tracing is becoming ever more valuable as users of liquid scintillators and internal gas counters improve their methods. Efficiencies as great as 71% are achieved with G-M tubes. Quartz-face photomultipliers and large-water-content scintillating solutions are pushing limits of detection to tritium-hydrogen ratios of 10^{-17}. Users of nature's favorite radiotracer compared their ways recently in Vienna under sponsorship of the International Atomic Energy Agency.

Counting efficiency of 71% is that of **R. L. Ely, Jr.** and **L. F. Ballard** (*125*),* who introduce roughly equal parts of water and Q-gas into a heated G-M tube. Total pressure in the tube is held at ~800 mm Hg, and up to 400 mm Hg can be water.

Another way to accomplish the same purpose is to reduce the water vapor to hydrogen by passing it over magnesium, mix it with a little propane and put the mixture into an electronically quenched G-M tube at atmospheric pressure (*17*). Using this method **G. Östlund** reports excellent plateaus, reproducibility and stability. He feels he can measure tritium-hydrogen ratios of 6×10^{-16} without enrichment.

To convert biological materials to a gas that will work well in internal-counting tubes, **J. Hasan** heats blood, muscle and liver in sealed tubes that contain powdered zinc, nickel oxide and anhydrous sodium carbonate (*47*). After 3 hr at 650° C the evolved gas provides stable and reproducible performance in brass-cathode tubes filled with methane and operated in either proportional or G-M region.

For short and simple determinations of relative activities, **R. Tykva** and **D. Grünberger** convert solid samples to acetylene (*71*). Counting is in argon-filled tubes of 60-cm³ volume.

To solve a problem that occurs with anticoincidence and internal quenching —poor background plateaus—use ethylamine or ether with hydrogen, says B. J. O'Brien (*74*). He compared many quenching gases, mixing them with hydrogen in a 300-cm³ counter. Hydrogen at 40 cm Hg quenched with ethylamine gave a background rate of 3 cpm and a flat plateau.

For those who prefer liquid-scintillation counting, speakers at the conference had information on better photomultipliers, the nature of background and sample preparation. **J. Sharpe** and **V. A. Stanley** reported on photomultipliers with efficiencies of ~15% and backgrounds of 30–180 cpm (*15*). Meanwhile **I. S. Boyce** and **J. F. Cameron** have found the following percentages for contributions to photomultiplier background: photocathode light from cosmic rays, 40%; photocathode light from K^{40}, 10%; light from tube operation, 33%; all other (try it) 17% (*59*). With improved quartz-face tubes they can now detect 10^{-6} mc/liter in 15-cm³ samples with 30-min counts.

Two methods were offered for combustion of organics to make them available for scintillation counting. **J. F. Eastham, H. L. Westbrook** and **D. Gonzales** wrap samples in filter paper and convert them in a flask containing suitable solvents and oxygen (*127*). **G. G. Steele** combusts biological samples with copper oxide alone in expendable Pyrex envelopes (*142*).

For biological materials **K. Halvorsen** uses direct dissolution in hyamine and counting of scintillating gels with a single phototube (*48*). **R. Bibron, G. Delibrias** and **M. Tamers** convert water samples into benzene for liquid-scintillation counting (*40*). After conventional conversion to acetylene the specimen is run through a heated quartz tube and two dry-ice traps. Some acetylene polymerizes to benzene, and this is purified first by distillation and then by gas chromatography. Adding naphthalene and a wavelength shifter produces a solution that permits counting atmospheric samples without enrichment.

To improve detection sensitivity **W. J. Kaufman, A. Nir** and **G. Parks** use high-gain quartz-face photomultipliers in direct contact with a dioxane-naphthalene-water solution (18.6% water) (*87*). With a total scintillator volume of 170 cm³ they achieve a sensitivity corresponding to 5.5×10^{-16} curie/liter, 6.9% efficiency, 52-cpm background.

* References are to numbers (preceded by "TTS/") assigned by IAEA to papers presented at the conference.

A Radioactive Control for Pigeon Population?

If you think the population explosion of the human race is a problem, consider what can happen to pigeons. The average pair mates monogamously and produces about six pairs of offspring per year. The offspring are ready to reproduce at six months; so off we go again. From each pair at the beginning of the year expect 24 offspring by Christmas, and assume a ten-year average life span. It is no wonder that in some cities the result is expensive cleanup problems and serious health menaces. In San Francisco, for example, the daily cost for cleaning a single small area is $25–50, and many areas go uncleaned as breeding places for bugs and bacteria.

Since we can solve insect-population problems with radiation (NU, Feb. '60, p. 74), why not try it on pigeons, asks Alfons Puishes, San Francisco patent attorney and nuclear-energy specialist. As little as 0.1 r/day of radiation exposure for several days will cause sterility in some animals; so a relatively light dose of radioactivity in food or drinking water might offer pigeon birth control in a simple and humane way. Monogamous mating offers a factor of two in favor. Radiation intensities would be quite harmless to humans—even those who feed pigeons.

So far the idea is in the feasibility-study stage. Before one can put it to work, some experimentation will be necessary on subjects like quantity of food, quantity of nuclide, body retention, distribution in the body, radiosensitivities, half-lives and energies. But Puishes feels that there is good promise of success.

Radiotracers Test Metal Cleaning

If you want metals that are very, *very* clean, radiotracers will test the efficacy of your cleaning methods with at least 10–100 times the sensitivity of other available tests, conclude G. D. Fatzer, J. M. Schroder and B. E. Blake of IBM, Endicott. Moreover tracers will test all contaminants whereas both of the other accepted tests depend on the ability of hydrophobic materials to break up thin water films.

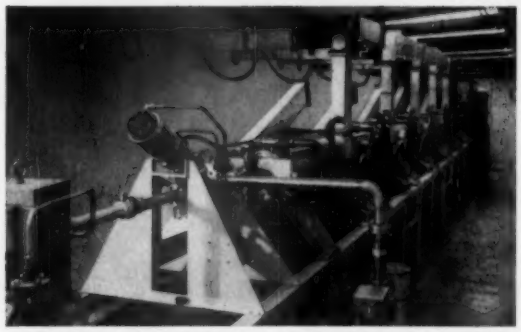
The IBM men examined two problems with both copper and gold samples: inorganic contamination from cleaning solutions and efficacy of their cleaning method for removal of polar organic contaminants. From potassium chromate in sulfuric acid the possible contaminants are sulfate and chromate ions. So Fatzer and his colleagues tagged the acid with S^{35} and the chromate with Cr^{51}. Calibration curves showed 3×10^{-8} gm as the minimal detectable amount of sulfate ion, and sodium-iodide counting gave 1.5×10^{-7} gm as the minimal detectable amount of chromium. Samples were 1.5 × 2-cm pieces of copper and 1.5 × 1.5-cm pieces of gold.

To follow organic contamination the men applied C^{14}-labeled palmitic and stearic acids to 1-cm^2 areas of both cleaned and uncleaned metal samples. Then they counted the samples in vials of scintillating liquid after various numbers of cleaning dips. Minimal detectable amounts were 3.2×10^{-9} gm (0.016 monolayer) of palmitic acid and 6.2×10^{-10} gm (0.003 monolayer) of stearic acid. The minimal amounts of stearic acid detectable by atomizer and water-break tests are, respectively, ~30 and 300 times as much as the radiotracer test detects. The radiotracer tests, moreover, can be made more sensitive by using materials of greater specific activities than were used by Fatzer and his coworkers.

Cleaning methods were capable of reducing contamination to the limits of sensitivity or near them. Copper surfaces electrocleaned as anodes in a potassium-chromate–sulfuric-acid solution acquire chromate and sulfate ions at concentrations less than the limits of detection. Toluene and chromic acid are good cleaning agents for the fatty acids; anodic electropolishing in chromic acid leaves 0.016 monolayer of palmitic acid and 0.003 monolayer of stearic acid after 2 min at 120°C.

High Voltage Engineering Corporation . . .

"CHARGED PARTICLES"



Rensselaer Polytechnic Institute — one of the most powerful accelerator neutron sources ever built, this linac will yield up to 10^{14} fast neutrons/sec, or a thermal flux of 10^{13} neutrons/sec/cm^2, with peak energy at 77 Mev, and peak pulse current of 800 ma. Primarily for neutron-time-of-flight and nuclear reactor research, the accelerator will also aid RPI's solid-state and radiation effect studies.

High Energy Linacs

Today's advances in particle accelerator technology are particularly illustrated by the microwave linear electron accelerator (linac). Spurred by experimental requirements for more intense bursts of high-energy electrons and neutrons contained within precise limits of time and space, High Voltage Engineering and Applied Radiation Corporation have sustained intensive development of linacs. The result has been consistent improvement in reliability, and a series of record-breaking machines for research and applied radiation projects.

Two research linacs of considerable sophistication are being installed at Yale University and Rensselaer Polytechnic Institute physics departments. The Yale machine is a five-section L-band accelerator, producing 28 kw of average radiation power and peak energies of 77 Mev. It will be used in a broad physical research program with emphasis on nuclear cross-section investigations. RPI's accelerator is an unusually powerful neutron physics research tool.

The accelerators of the near-future are exemplified by the machine now being built for the U.S. National Bureau of Standards. This linac, designed to performance specified by the NBS, will produce electron beam peak energies up to 150 Mev. Its 40 kw power output at 100 Mev will be greater than any previously obtained from a linear accelerator.

Applied Radiation

As a powerful source of ionizing radiation, the linac is also a prime candidate for industrial radiation programs where electron penetration above 3 Mev is required. For example, most surgical sutures used today (made by Ethicon, Inc., a division of Johnson & Johnson) are electron-beam sterilized in aluminum-foil packages by industrial linacs operating on a two shift production basis.

Development at High Voltage Engineering and ARCO has led to compact microwave electron accelerators for x-ray inspection and deep-x-ray therapy. High energy x-ray linacs can radiograph through two feet of steel or nondestructively inspect our biggest solid fuel rocket engines. Medical x-ray linacs now provide the radiologist with a new precision therapy tool for treating deep-seated malignancies.

If you see the possibilities for accelerators in your research program or have a challenging radiation application, we'd be pleased to receive your inquiry.

HIGH VOLTAGE ENGINEERING CORPORATION
BURLINGTON, MASSACHUSETTS, U.S.A.

APPLIED RADIATION CORPORATION

HIGH VOLTAGE ENGINEERING (EUROPA) N.V.

Reliability from experience with over 250 accelerators in the field

Solving Design Problems for Food Irradiators

Since irradiators are in their infancy, whoever undertakes to design one must proceed without benefit of experience. The first of the following articles tells how one group of designers determined dose rates with a combination of model measurements and computer calculations.

The second article tells how they met the basic design dilemma: the choice between best use of radiation (large volume of product, small source) and best treatment of product (uniform dose rates, large source, small volume of product, a many-pass system).

1. Dose Rates from Rectangular Plaques

by FRED G. MOOTE,* *Curtiss-Wright Corp., Princeton, New Jersey*

In constructing irradiators one must consider how the design criteria of a gamma source affect its dose rate. We have made computations for large rectangular plaque irradiators and then tested our results against High Intensity Food Irradiator (HIFI) models.

These tests show that our analytical procedure gives depth-dose curves within 3–5% of the values one gets from experiments. Therefore we can offer you a set of analytical procedures with which you can easily determine depth dose rates within two mean free paths of the source.

Radiation Flux Formulas

The geometrical models usually connected with gamma-attenuation formulas deal with idealized sources such as points, infinite lines or planes (*1–4*). Although these models give simple approximations with accuracies within a factor of ten for massive shielding calculations, one needs a more precise knowledge of dose rate for radiation-processing applications. Thus in calculating dose rate, one must consider finite source dimensions including source thickness.

The dose rate in rads per hour from an infinite slab source is given by

$$D = \frac{2\pi k S_v}{\mu_s^2} [E_2(\mu_w x_w) - E_2(\mu_s x_s + \mu_w x_w)] B(\mu x)$$

(See box for symbols.)

It is usually more convenient to compute dose rate from the infinite-plane-source formula,

$$D = 2\pi k S_a E_1(\mu x) B(\mu x)$$

Except for the region very close to the source slab, the agreement between the two formulas is good for reasonably small source thicknesses. In practice, the plane-source formula is adequate outside the cladding. For accurate dose rates within the cladding one represents rates at the surface of the unclad source by $E_1(\mu_s x_s/3)$. In addition, the formula for an infinite plane source is accurate for $\mu_w x_w \geq \mu_s x_s$ and graphical interpolations can be made between these values. One finds that the dose rate is always finite even though the function $E_1(\mu x)$ becomes infinite as absorber thickness (μx) approaches zero. Thus the formulas for infinite planes can be applied to practical source thicknesses.

Solid Angle of Source

Dose rate for a finite source is proportional to the solid angle subtended by the source, which is always less than the 2π steradians of an infinite source. From Fig. 1 one can compute the solid angle subtended by a finite rectangular plaque source with length L and width W at a distance Z from the midpoint of the rectangle. The curves give the solid angle subtended by the source in multiples of 2π steradians ($\omega = \Omega/2\pi$). The dose rate for a finite slab is then given by

$$D = 2\pi\omega k S_a E_1(\mu x) B(\mu x) \quad (1)$$

Buildup Factor

The remaining quantity to be determined, and the most difficult to calculate analytically, is the buildup factor for scattered radiation (*4–7*).

There are three different ways of getting expressions for buildup factor for a plane isotropic source (*4*). The first approach is to integrate the dose rate from a point source over an infinite plane. In the second method one uses an exponential for the buildup factor (*7*). A third method in which one uses Goldstein's energy-conservation theorem, leads to a simple linear approximation for the buildup factor. These three expressions are shown graphically as Curves D, E and F in Fig. 2; Curves A, B and C show the corresponding point-source buildup factors. Beyond two mean free paths, the various analytical expressions appear to diverge seriously, but if the curves are extended out to about ten mean free paths, they all converge closely again.

Experimental values from measurements made with HIFI models are plotted as Curve G (*8*). This curve, represents the experimental dose rate divided by solid angle, exponential integral and constants. The values in Curve G are larger than those for any of the analytical expressions and they diverge more than the others at absorber depths greater than two mean free paths. This divergence, however, is not of serious practical significance since this depth represents two or three package thicknesses from the source; at this point the dose is a small fraction of the total absorbed dose. Since the absorption coefficients increase very steeply at the low-energy range of the

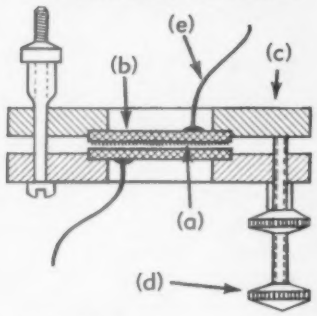
* PRESENT ADDRESS: Alco Products Inc., Fort Belvoir, Virginia.

Symbols

- k = Conversion factor to dose-rate units
- S_v = Source activity/unit volume (curies/cm³)
- μ_s = Source absorption coefficient (cm⁻¹)
- $E_2(\mu x)$ = Second order exponential integral
- $\mu_w x_w$ = Absorber thickness (mean free paths)
- $\mu_s x_s$ = Source thickness (mean free paths)
- $B(\mu x)$ = Buildup factor
- S_a = Source activity/unit area (curies/cm²) $= \frac{S_v \mu_s x_s}{\mu_s}$
- $E_1(\mu x)$ = First order exponential integral
- μx = Effective absorber thickness (mean free paths) $= \mu_s x_s/2 + \mu_w x_w$
- $b = \Sigma \mu_i x_i$
- $\omega = \Omega/2\pi$

ORTEC

NEUTRON SANDWICH SPECTROMETERS



(a) Li^6F
(b) Silicon wafer
(c) Lavite ring
(d) Positioning screw
(e) Electrical leads

- Li^6 (n, a) T reaction for fast neutron spectrometry
- Minimum mass
- Non hydrogenous
- 1½" diameter
- No high voltage
- For use in air or vacuum

Oak Ridge Technical Enterprises Corporation
Box 524
Oak Ridge, Tenn.

For Further Information Check:
- ☐ Neutron spectrometers
- ☐ RF ion sources & accessories
- ☐ Surface barrier detectors
- ☐ Neutron converter foils

Write:
Oak Ridge Technical Enterprises Corporation
Box 524, Dept. D
Oak Ridge, Tenn.

PURITY as high as 99.9975%
with 'LINDE' RARE GASES

MONATOMIC
DIATOMIC
RADIOACTIVE
SPECIAL MIXTURES
COMBINATIONS

All LINDE atmospheric gases are produced under continuous Mass Spectrometer Control—offering the *highest possible purity* for nuclear processes.

Huge production facilities and a widespread distribution system make it possible for LINDE to supply large quantities of these gases and mixtures throughout the country— in bulbs, cylinders, or liquids via trucks. These unique capabilities are the result of 50 years of pioneering research and development work in rare gases and their behavior.

LINDE gases serve as refrigerants, aid in radiation detection, and effectively shield materials and equipment. In reactor assemblies, they serve as purge gases, assist in heat transfer and fuel element processing, and protect EBR-type reactor piles. In instrumentation they are used as fill-gases, insulation for high-voltage terminals, and in gaseous scintillation counters and radiation intensity measuring devices.

For complete data on gases, write for a copy of F-1002C, *"Linde High Purity Gases."* Address Dept. NU-07, Linde Company, Division of Union Carbide Corporation, 270 Park Avenue, New York 17, N. Y. *In Canada:* Linde Company, Division of Union Carbide Canada Limited, Montreal 7.

LINDE COMPANY
UNION CARBIDE

LINDE and UNION CARBIDE are registered trade marks.

scattered-radiation spectrum, the divergence may be due to the energy dependence of the detection system. These measurements are also taken at lower dose rates; at these dose rates experimental errors, background levels and scattering from nearby structures all contribute to the uncertainty at greater depths.

Curve F is the analytical expression that fits the experimental data most closely within two mean free paths of the source and beyond as well. This linear-approximation curve, calculated from Goldstein's energy-conservation theorem, is written for a Co^{60} plane source in a water medium as

$$B(\mu x) = 1 + \frac{2(\mu - \mu_a)}{\mu_a}\mu x = 1 + 2.24\,\mu x \quad (2)$$

Because of its close fit to the analytical curves, we decided to use Curve F, or Eq. 2, as the best value for buildup factor from a plane source. In Fig. 3 this expression is combined with the exponential integral to give the over-all attenuation factor $E_1(\mu x)B(\mu x)$.

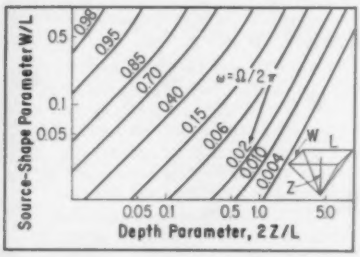


FIG. 1. CURVES GIVE SOLID ANGLE subtended by finite source. Angle is proportional to dose rate for source

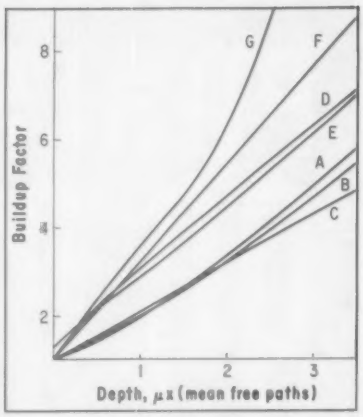


FIG. 2. BUILDUP FACTORS for gammas in water. Analytical Curves A, B and C are from point sources; D, E and F are from plane isotropic sources. Curve F gives closest fit to experimental Curve G

Calculating Dose Curve

Using Eq. 1 and Figs. 1 and 3, one can easily calculate a depth-dose-distribution curve for a given geometrical arrangement of rectangular plane sources. From Fig. 1 one gets the solid angle subtended at various distances from the source; these are then plotted on semilogarithmic graph paper. One gets from Fig. 3 the over-all attenuation factor $E_1(\mu x)B(\mu x)$ at the desired absorber depths including the cladding thickness and half the source thickness and then plots them on the same graph. The product of these two functions and specific activity and constants gives the dose rate at each depth as defined in Eq. 1.

Depth-dose curves calculated in this way agree well with experimental measurements. The discrepancy is represented by the difference in buildup factors shown in Fig. 2. In general the calculated values give conservative results—a dose rate ~3–5% lower than measured values. If one does not verify calculations with experimental models, these percentages are comfortable safety factors for any new source design.

* * *

This work was supported by the AEC under contract AT(04-3)-200. Figure 2 was supplied by C. Eisenhauer of the National Bureau of Standards.

(Bibliography is on page 110)

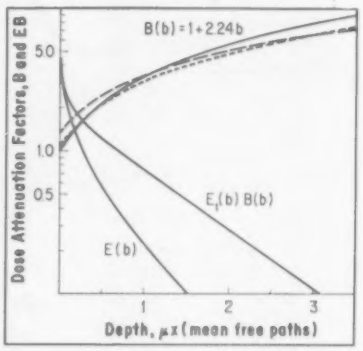


FIG. 3. ATTENUATION FACTOR contains analytical buildup factor for Curve F, B(b), and exponential integral, $E_1(b)$

2. Three-Plaque, Two-Pass Irradiator

by JOHN L. DONOVAN,* *Curtiss-Wright Corp., Princeton, New Jersey*

Practical food irradiators must meet certain criteria of cost, efficiency and processing speed. Faced with a specific set of requirements for such an irradiator (see box) we found by computation and experiment that a three-plaque, two-pass design is best.

In our experimental method we used a small scintillation detector to study dose-rate patterns in a water tank that simulates food packages irradiated by plaque-shaped sources. By studying the dose rate from different sources, we could then determine what source shape should be used, how many plaques there should be and what design considerations were most important. With the detector we could make rapid measurements with full-sized irradiator models that had 10^{-3} of the activity intended for the final irradiator.

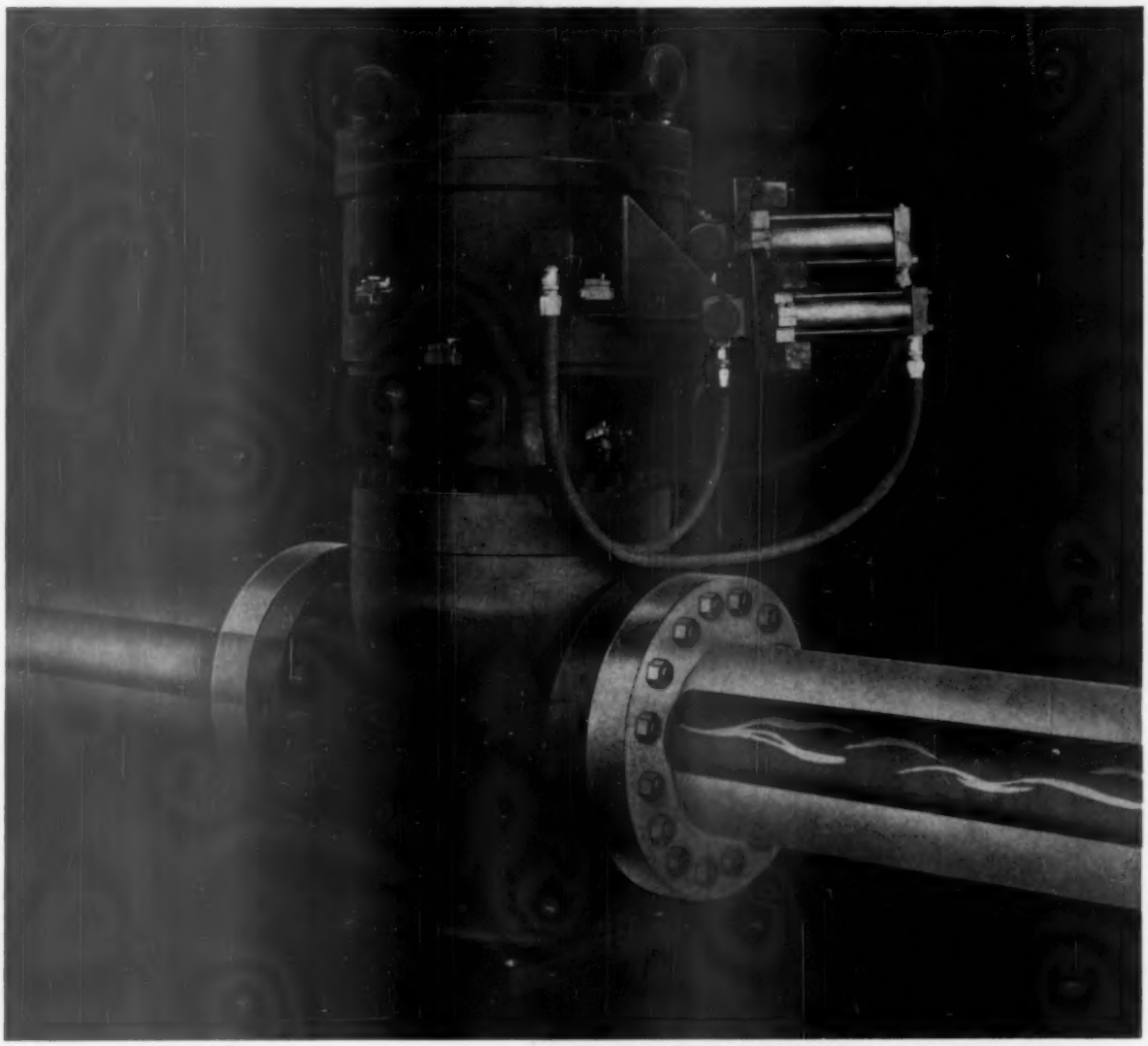
In our analytical approach we used a three-dimensional code with an IBM-704 computer to study deposited energy throughout the irradiator. The

* PRESENT ADDRESS: Department of Nuclear Science and Engineering, University of Michigan, Ann Arbor, Michigan.

Specifications for the HIFI Irradiator

- Packages must be exposed to 8,000–5,000,000 rads while in irradiator.
- Dwell time for 5 megarads must not exceed 65 min.
- Irradiator should process packages at a minimum rate of 3,000 lb/hr for doses up to 2 megarads. For larger doses irradiator output should be at least 3 ton-megarads/hr.
- Radiation chambers should be designed to accommodate packages ranging in size from symmetrical items of 25 in.^{3} to nonsymmetrical items of 30 ft^3.
- Temperature of radiation chambers should be controlled within 10° F over range from ambient temperature to +10° F. Products may enter irradiator at temperatures from −20° F to +170° F.
- Dose variation in packages must be small. Maximum acceptable dose variation is 25% of required amount.

ALLIS-CHALMERS



Rotovalve is an Allis-Chalmers trademark.

Featured 8-in. Rotovalve stands 7 ft high and weighs 50,000 lb. Hydraulic operator works at a pressure of 3000 psi . . . a speed of 1/10th second!

"Putting a stop" to 2500 psi at 2500 F

...here's the valve that does it with ease!

This 8-in. *Rotovalve* takes extreme conditions in stride . . . handles 2500 psi at 2500 F. Constructed of chrome-moly steel, it employs internal air cooling to maintain valve temperature at 1000 F despite the *far higher* heat of the liquid or gas being handled.

Allis-Chalmers cone valves *seat even tighter with use* . . . feature lantern ring with double packing, pressurized with the line fluid or purged to a bleed tank at lantern ring. Both standard and special *Rotovalve* units have proved their reliability in thousands of applications, under widely varying conditions.

Any time you face a valving problem, call on your Allis-Chalmers representative. He's equipped to supply "specials" engineered exactly to your application. And he also offers you a complete line of Rotovalve *units and butterfly valves for conventional uses. Contact him for information, or write* **Allis-Chalmers,** *Hydraulic Division, York, Pa.* A-1394

"There are few facts in science more interesting than those which establish a connection between heat and electricity."
—Joule

James Prescott Joule
1818-1889

The facts that fascinated J. P. Joule in the nineteenth century are vital at Los Alamos in the twentieth—freshly combined with facts he never dreamed of. Heat from the Omega West Reactor, directly converted by the plasma thermocouple, drives electric motors. Electricity from the Zeus capacitor bank produces thermonuclear temperatures, partly by the familiar process called joule heating. The Los Alamos Scientific Laboratory is proud to acknowledge its debt to great men who have found facts "interesting."

For employment information write:
Personnel Director, Division 61-57

los alamos
scientific laboratory
OF THE UNIVERSITY OF CALIFORNIA
LOS ALAMOS, NEW MEXICO

Food Irradiators

This article starts on page 102

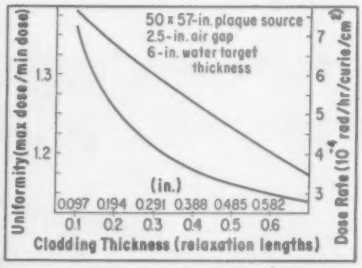


FIG. 1. DOSE RATE VARIES with cladding thickness as shown by experiments. Dose rate was measured at 3 in. depth

code confirmed the experimental program and provided data on design efficiency.

Experimental Source Design

After considering many source-plaque geometries, we chose a rectangular design because with it we could get improved uniformity and energy-utilization efficiency over other designs. In addition, we could irradiate larger food packages.

Having chosen the design, we experimented with rectangular plaques that contained cobalt strips between two sheets of aluminum. These strips, 10 in. long, 0.8 in. high and 0.030 in. thick were activated to 0.1 μc/gm. To calibrate the strips we dissolved samples of the source in liquid and then counted them in a well scintillation counter calibrated with standard Co^{60} solutions.

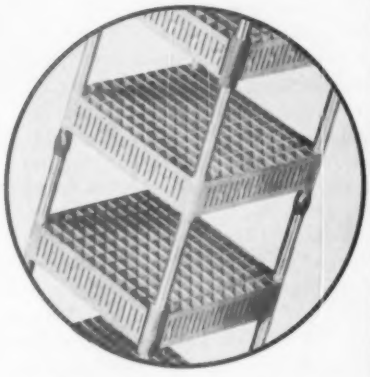
Our detector, calibrated daily in air

Three-Plaque, Two-Pass Design

Plaque length	50 in.
Plaque height	50 in.
Cobalt thickness	
Inner plaque	0.130 in.
Outer plaque	0.060 in.
Cladding thickness	
Inner plaque	0.225 in.
Outer plaque	0.100 in.
Cobalt specific activity	26 and 39 c/gm
Food-package height	40 in.
Conveyer speed for 5-megarads	2.35 in./min
Air gap	2.5 in.
Dose factor to food packages	71, 60, 10 kilorads/hr/curie/cm² (avg. 49 kilorads/hr/c/cm²)
Total source activity	2.5 Mc Co^{60}
Gamma energy utilisation efficiency	22%

STALKER PRODUCED

HONEYCOMB GRID ASSEMBLY for ENRICO FERMI FAST NEUTRON BREEDER REACTOR*



Stalker's skilled personnel plus Stalker's exclusive PROVEN ORTHOBRAZE METHODS of stress-free forming and high temperature brazing of intricate sheet metal assemblies assure a high quality assembly which will meet strictest requirements.

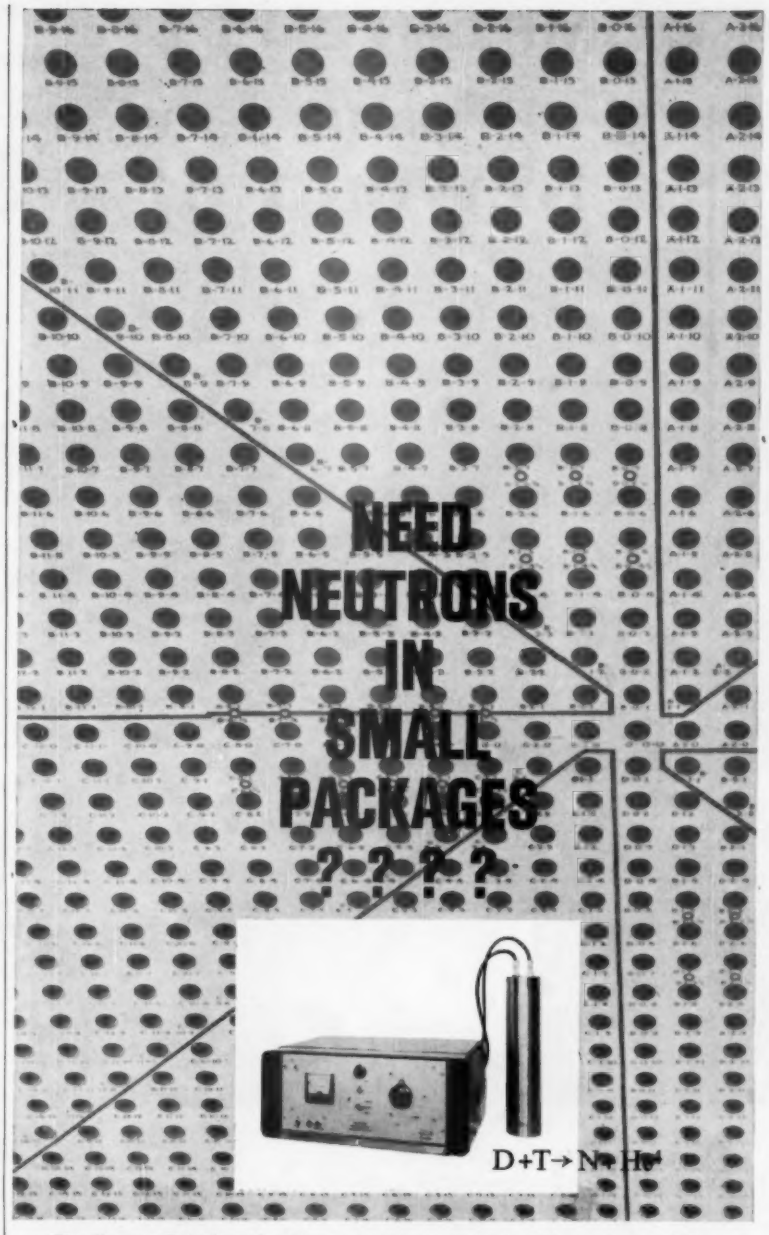
Highly adaptable to many precision stainless steel or super alloy fabrications — Stalker techniques are ideally suited for the production of honeycomb grids for reactor application.

Stalker engineering, prototype development and production facilities are available for customer use.

*(Lagoona Beach, Michigan)

THE STALKER CORPORATION
905 Woodside Ave.
Essexville, Michigan

Phone: Bay City — Twinbrook 3-7562



The Kaman Pulsatron for physics research and education uses specially-designed H^3 foil targets developed and produced by United States Radium Corporation.

U.S. Radium's tritium foil makes possible the generation of high neutron fluxes in a compact, versatile unit eliminating the need for costly reactor installations. Tritium foil, bombarded by deuteron projectiles, produces copious supplies of neutrons for activation analysis, oil well logging, gas chromatography and related applications.

Tritiated foil targets are immediately obtainable from United States Radium stock. Standard backings are either stainless steel or copper; standard tritium concentration is 1 curie/sq. in. Custom targets available on special order.

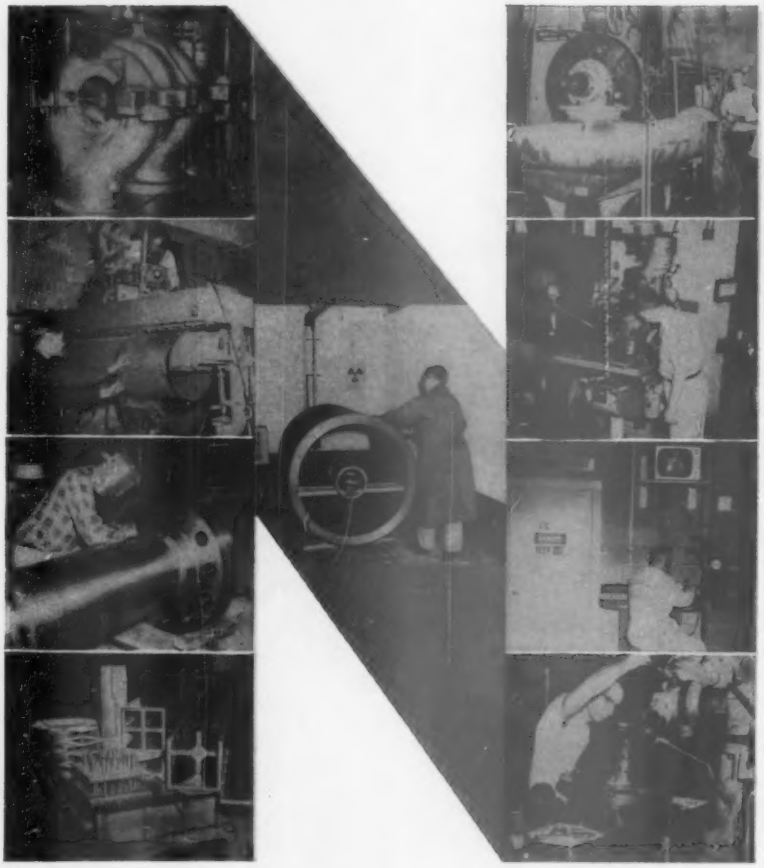
Request Bulletins 20.70 and 20.70B.

united states radium corporation

MORRISTOWN, N. J.

Offices: Chicago, Illinois and North Hollywood, Calif. Subsidiaries: Radelin Ltd., Port Credit, Ont., Canada and U. S. Radium Corp. (Europe), Geneva, Switzerland.

A COMPLETE
Start-to-Finish Service
by NEWBROOK



NEWBROOK is an experienced organization with research, development and production facilities and capabilities to render a Start-to-Finish service.

We have a small, efficient plant, completely integrated with machines, men and "know-how." Our engineering and technical specialists have an extensive background in mechanical, electrical and hydraulic design and production. Our welders are certified and skilled in the welding of all the special metals used in atomic and missile components.

Newbrook offers you quality, reliability and delivery "on time." Let us quote on your requirements.

NEWBROOK is now producing nuclear hardware components, pressure vessels, vacuum equipment and other atomic products.

Our customers include nuclear and atomic contractors working on A.E.C. projects.

NEWBROOK is well known for its part in the production of Turbines, Launchers, Hydraulic Pumps, Shields, Starters, Detector Rod Mechanisms for Atomic Piles, Sub-Assemblies for Nuclear Reactors, Testing Devices, Vacuum and Pressure Furnaces . . . and many more.

NEWBROOK
MACHINE CORPORATION
SILVER CREEK • NEW YORK

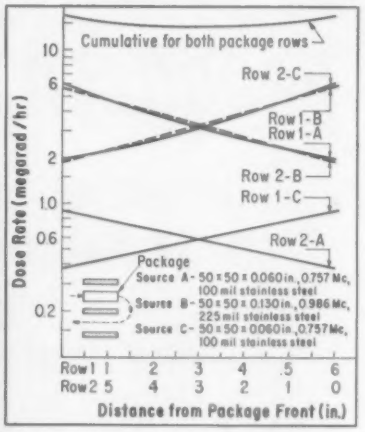

Cumulative for both package rows
Row 2-C
Row 1-B
Row 1-A
Row 2-B
Row 1-C
Row 2-A
Dose Rate (megarad/hr)
10
6
2
1.0
0.6
0.2
Package
Source A- 50 x 50 x 0.060 in., 0.757 Mc, 100 mil stainless steel
Source B- 50 x 50 x 0.130 in., 0.986 Mc, 225 mil stainless steel
Source C- 50 x 50 x 0.060 in., 0.757 Mc, 100 mil stainless steel
Row 1 1 2 3 4 5 6
Row 2 5 4 3 2 1 0
Distance from Package Front (in.)

FIG. 2. CUMULATIVE DEPTH DOSE distribution for three-plaque, two-pass source design based on experimental results

and periodically in water, was a $\frac{5}{8} \times \frac{3}{4}$-in. anthracene crystal capable of measuring dose rates of 0.5–20 mr/hr.

From our experimental investigations with different sized source plaques, we found that the important design considerations for an irradiator are (1) the air gap between source and target material, (2) cobalt and cladding thickness, (3) plaque height and vertical source shaping above and below target material and (4) edge effects encountered as the food packages move into and out of the radiation field in front of the sources.

We also investigated cobalt thicknesses of 0.030 and 0.090 in. and stainless-steel cladding thicknesses from 0 to 0.700 in. (Fig. 1).

Vertical source overlap and source shaping based on specific-activity variation held the vertical dose-rate ratio (maximum dose/minimum dose) to 1.00 ± 0.02 for a 6-in. water thickness. Thus maximum permissible dose-uniformity variation of 1.25 was applied to the 6-in. thickness of a package. If the food package was moved lengthwise past the plaques, a complete dose uniformity resulted in this direction.

Three-Plaque Design

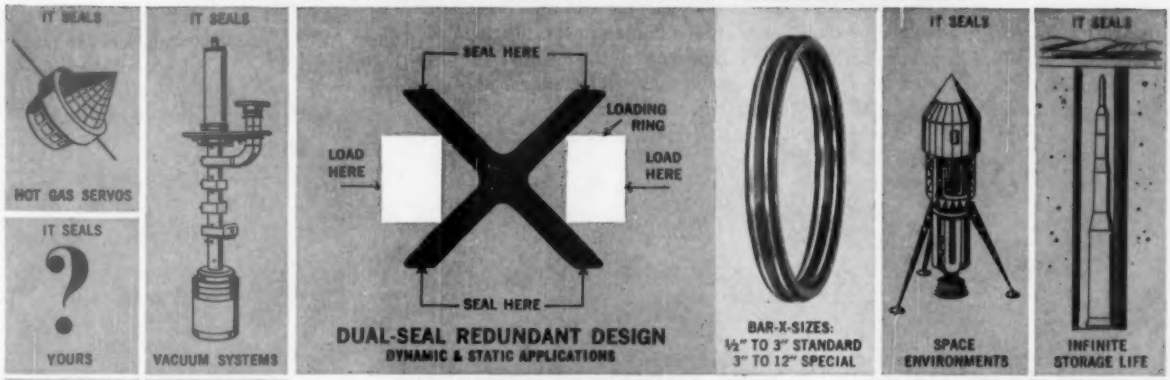
Our decision to use a three-plaque, two-pass design was based on the necessity of providing complete sterilization and on the problems of irradiating all particles in a movable liquid medium.

The sterilization dose is generally accepted as 12 D (D is radiation needed to reduce viable microbial population to one tenth). In general, for gamma

BAR-X® SEALS EVERYTHING

AT TEMPERATURES FROM −400° F TO +1500° F!

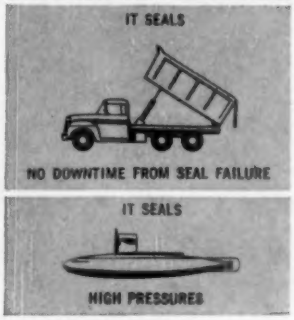
ANY FLUID—GAS—FUELS—WATER—LIQUID METALS—CRYOGENIC FLUIDS—CORROSIVE FLUIDS
ANY SYSTEM—HYDRAULIC—PNEUMATIC—VACUUM—CRYOGENIC—NUCLEAR



NO CATASTROPHIC FAILURES
INFINITE STORAGE LIFE
UNPRECEDENTED SERVICE LIFE

Eliminates critical downtime ■ Very high and very low pressure ■ Easy, foolproof installation (not a mechanism) ■ All-metal—non-contaminating ■ Stable, symmetrical design

WRITE TODAY FOR THE FULL STORY! **SALES ENGINEERS IN PRINCIPAL CITIES.**



Wiggins

E. B. WIGGINS OIL TOOL CO., INC., Dept. H1
3424 E. Olympic Blvd., Los Angeles 23, Calif.
TWX 1403U, Phone AN 9-0181

---

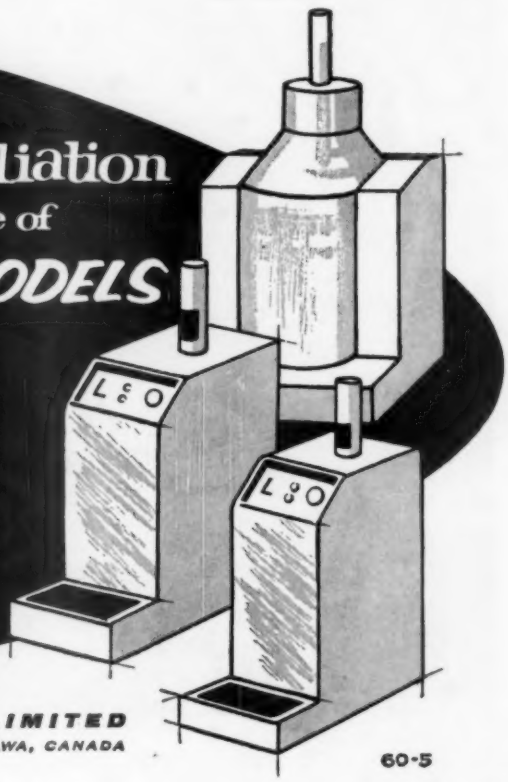
for Cobalt 60 Irradiation
you now have a choice of
3 GAMMACELL MODELS

Select the model and dose-rate to suit your research program and your budget.

GAMMACELL 220	GAMMACELL 200	GAMMACELL 100
Dose rates up to (r/hr)		
2×10^6	3×10^5	3×10^5
Irradiation Chamber size (inches)		
6 dia x 8⅛	3½ dia x 5½	1½ dia x 4½

All 3 models are completely self-shielded, are inherently safe and convenient to operate, and permit the irradiation of solids, liquids or gases under a wide variety of environments.

For complete information please write to:



ATOMIC ENERGY OF CANADA LIMITED
COMMERCIAL PRODUCTS DIVISION, P.O. BOX 93, OTTAWA, CANADA

60-5

radiation, D is ~400,000 rads. Therefore, to satisfy both the dose and uniformity requirements, the irradiator design had to ensure that all the food received at least 4.8 megarads and not more than 6 megarads.

We considered sources with 1–5 plaques. We found that any system in which food passes on the outside of a plaque is unacceptable because some of the particles free to move in a liquid might always occupy positions farthest from the source and thus might not receive the minimum sterilization dose. For this reason, we rejected the one-plaque system. Mechanical and construction considerations as well as the dwell-time requirement indicate that two or three plaques will irradiate best.

To meet the need for between-plaque package travel, we found that we had to use a 2.5-in. air gap so that packages 8 in. thick could be irradiated. Since this gap is larger than that in our original design, we found that we should increase the source overlap ~1 in. if we were to have uniform source overlap. By using higher-specific-activity cobalt at the top and bottom of the plaques, we shaped the source to make it more efficient. The efficiency (radiation power usefully absorbed/total radiation power) of our three-source, two-pass system is ~22% based on energy absorption in food. If longer irradiation times become acceptable, the design of this system can later be made still more efficient by adding replenished cobalt at the top and end of the plaques. The cumulative depth-dose distribution for the system is shown in Fig. 2 and the table describes the irradiator.

Monte Carlo Computation

The Monte Carlo code together with an IBM-704 computer uses random probability to decide where a gamma ray will be born. Then, obeying the laws of gamma-ray scattering and absorption, it deposits energy from each event throughout the system. By recording the energy deposited in small volumes of the target region, one gets dose rates throughout these regions using the relationship between absorbed energy and dose.

We used this code to investigate the dose-rate variation in targets similar to those we studied experimentally. Within the limits of statistical accuracy of the code, the experimental results and the Monte Carlo analysis showed good agreement.

* * *

The author gratefully acknowledges the assistance of D. C. Brunton for over-all program guidance, P. I. Amundson for helping to develop the detector system and K. L. Rooney for modifying the three-dimensional code for this program.

This work was performed under AEC contract AT(04-3)-200.

BIBLIOGRAPHY

1. S. Glasstone, "Principles of Nuclear Reactor Engineering" (D. Van Nostrand Co., Inc., Princeton, N. J., 1955)
2. T. Rockwell, ed, "Reactor Shielding Design Manual" (D. Van Nostrand Co., Inc., Princeton, N. J., 1956)
3. B. T. Price, et al., "Radiation Shielding" (Pergamon Press, Inc., New York, 1957)
4. H. Goldstein, "The Attenuation of Gamma Rays and Neutrons in Reactor Shields" (U.S. Govt. Printing Office, Washington, 1957)
5. H. Goldstein, J. E. Wilkins, Jr., "Calculations of the Penetrations of Gamma Rays," NYO-3075 (U. S. Govt. Printing Office, Washington, 1957)
6. M. J. Berger, J. Doggett, *J. Research NBS* **56**, 89 (1956)
7. L. B. Spencer, M. J. Berger, *Radiation Research* **10**, 552 (1959)
8. J. L. Donovan, NUCLEONICS, this issue

Linear Micro-Micro Ammeter

Features:
Twenty ranges.
Lower drift.
High accuracy.

Model R660

The Model R660 is useful wherever high sensitivity and accuracy with long term stability are required in D.C. current measurements. Examples of the applications of the Model R660 include measurement of the current from ionization chambers and phototubes in radiation field determinations, reactor control, radiation monitoring systems, thickness gauging and liquid level control, measurements of radioactivity in tracer work and the evaluation of radioactivants in neutron measurements.

The circuit is a hybrid design with an electrometer tube input and all solid state circuitry thereafter. A 5886 electrometer tube is utilized to indicate null conditions at the circuit input. Current is fed back through a high resistance to keep the input voltage near ground potential. This arrangement produces a low impedance and greatly reduces drift due to changing electrometer tube characteristics. The output signal is then obtained by measuring the voltage across the high feedback resistance. A high stability, temperature compensated, transistorized amplifier with the electrometer tube is arranged so as to produce almost 100% feedback. The result is a compact precision instrument with outstanding characteristics.

Specifications

RANGES:	Twenty ranges are provided from 3 x 10^{-3} to 1 x 10^{-12} amperes full scale
INPUT:	Positive or negative as selected by a front panel toggle switch
METER:	4-1/2" mirror scale
ACCURACY:	± 2% of full scale on 3 x 10^{-3} to 1 x 10^{-8} ampere range; ± 4% of full scale on more sensitive ranges
DRIFT:	Less than ± 2% of full scale per week after initial warm-up of less than 10 minutes
ZERO CHECK:	A front panel push button switch allows zeroing on any range without disturbing the circuitry.
OUTPUTS:	Suitable output signals are provided for driving a one ma full scale recorder and either a 10 mv or 100 mv full scale recorder.
POWER:	115 V, 60 cycle, 7 watts.

Radiation Technology, Inc.
057 ANTONE STREET NW • ATLANTA 18, GEORGIA • AREA CODE 404 873-2632

Price $495

HOW IS YOUR NUCLEAR VISION?

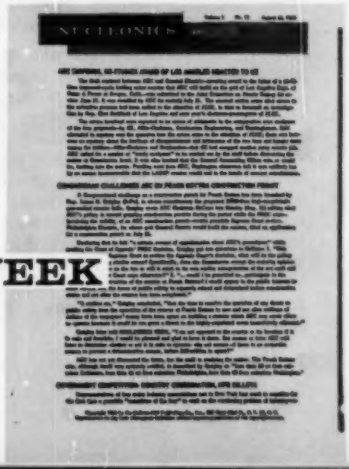
Is the industry out of focus.....or is the picture clear?

Do you see a world-wide view.....or are you left in the dark?

Do you get scanning eyestrain.....or is your area pinpointed?

Are you foresighted...or not a NUCLEONICS WEEK subscriber?

In the above test, "the eyes that have it" are those of the NUCLEONICS WEEK subscriber. These well-informed people have instilled in us the proud feeling that NUCLEONICS WEEK has already become the leading weekly authority in nuclear news coverage. In the first year and a quarter since its official start of publication on April 28, 1960, NUCLEONICS WEEK has seen development of a demand that has surpassed our own fondest hopes — and there is no let-up in sight! *How is your nuclear vision?*


NUCLEONICS

Make a date this week with... NUCLEONICS WEEK

330 WEST 42nd ST., NEW YORK 36, N.Y.

Advertisement

"Radiation resistant and high temperature wire is finding new and interesting applications almost every day", says J. E. Ferrer, radiation engineer. "A prominent manufacturer of neutron counters has used 90 ohm coaxial wire in the borontrifluoride chambers with excellent results.

In other areas 1,000°F instrument wire using oxygen-free nickel-clad conductors has been employed to provide interference-free signals to the control panels of the nuclear reactor of the S.S. Savannah, the world's first atomic powered surface vessel. Similar high temperature wires are now used in the SNAP project, the system for providing auxiliary power for satellites through atomic generators.

Of particular interest is the multiconductor cable designed for and used in the KIWI —.A prime reactor. This application called for a cable which would not only furnish power, but provide control of a locomotive moving in and out of the reactor. The cable resists intense heat and radiation and, at the same time, is able to withstand continuous flexing and scuffing and abrasion."

The special cables mentioned above were designed and developed by BIW engineers. Since 1954 they have been working on radiation monitoring and control cables. From this tremendous backlog they have developed methods and techniques which lead to quicker solutions of cable problems involving extreme heat and radiation, as well as moisture, sub-zero temperature, high pressure and other unusual problems.

BIW is noted for the ability to work closely with clients, produce designs and provide short prototype or long runs at realistic figures. We have many designs on file which may be the answer to your present problems. Or, if you need wire or cable with particular characteristics to meet unusual environments we will be happy to produce a cable to satisfy your exact requirements. Write or call Boston Insulated Wire & Cable Company, 25 Bay Street, Boston 25, Massachusetts.

NUCLEAR BOOKSHELF

Reactor Analysis

By R. V. MEGHREBLIAN and D. K. HOLMES (McGraw-Hill Book Co., Inc., New York, 1960, $19.50, 808 pages)

Reviewed by G. I. MARCHUK, Academy of Sciences of the USSR

"Reactor Analysis" is devoted to questions on the general theory of nuclear reactors. Although a great number of monographs and books on the theory and methods of nuclear-reactor calculation have been published during the last few years, new books about nuclear power generation are still significant events in science. This is because the development of nuclear power is proceeding at an accelerated rate and therefore questions on reactor theory and calculations acquire a special role in forming and solving new technological problems.

In addition, since until now reactor theory was formed mainly as an independent branch of mathematics, physics and engineering, the present problem is not only to obtain new theoretical and practical results but also to analyze them thoroughly and methodically.

"Reactor Analysis" is a quite successful attempt to compose a systematic course of reactor-theory study based on wide use of modern scientific accomplishments in this field. The book fills a void in literature between elementary and theoretical foundations of nuclear power generation. On the one hand it approaches in ideology "Elements of Nuclear Reactor Theory" by S. Glasstone and M. Edlund; on the other hand "Physical Theory of Neutron Chain Reactors" by A. Weinberg and E. Wigner.

The chief emphasis in the book is on reactor theory. The mathematics used by the authors is in most cases a means of obtaining physical results, the interpretation of which is the basic content of the book. Because of this, the mathematics is fully comprehensible to a wide circle of physics and engineering students.

To make the subject attractive, the authors discuss only the simplest theoretical models with a detailed analysis of the results. The simple models are used, however, to analyze rather complicated theoretical questions. Such a method is undoubtedly effective in explaining the basic principles of a reactor course.

In the chapters of the book the authors successfully explain the theory of the reactor's temperature coefficient—a coefficient with great significance to nuclear power-plant design. Interesting results are given for the theories of resonance capture in which an integral equation is used for the average neutron flux in the block of a heterogeneous reactor in the resonance energy region; various approximate explanations are given for the solution of the equation. The Feinberg-Galanin theory of heterogeneous reactors is well explained. Significant results are cited in the chapter on reactor kinetics.

The book also deals with design and calculation questions—the methods of spherical harmonics, of Serber-Wilson, Feynman-Welton, Goertzel-Selengut, and the multigroup method of reactor calculation.

Apparently the size of the book did not permit the authors to devote enough space to the theory of conjugate functions and their application to reactor calculations even though these questions receive thorough development in the works of Wigner, L. N. Usachev and Hurwitz and are convenient mathematical methods for all physical interpretations.

Insofar as the book is basically devoted to general questions of reactor theory, it can be usefully complemented by Galanin's book, which discusses many practical applications of the theory to reactor calculation.

The authors might have given more space to numerical methods of reactor calculation, which are the basis for designing nuclear power generation stations. This, undoubtedly, would have made the book more valuable from a practical point of view.

In addition, it is unfortunate that the book does not have enough material on the results of Soviet investigations in reactor theory.

In conclusion, "Reactor Analysis" is a valuable addition to the theory of nuclear power generation. At the same time, the book may be recommended as a textbook for persons just familiarizing themselves with the theory of nuclear reactors.

Thermal Reactor Theory

By A. D. GALANIN, translated by J. B. Sykes, 2nd edition (Pergamon Press, New York, 1960, $15, xiv + 412 pages)

Reviewed by RAYMOND L. MURRAY, Department of Physics, North Carolina State College, Raleigh, N. C.

Differences in notation and approach often make Russian reactor articles

difficult for Americans to understand. A perusal of Galanin's book is therefore helpful since the symbolism and approach are clarified by studying familiar age-diffusion criticality theory.

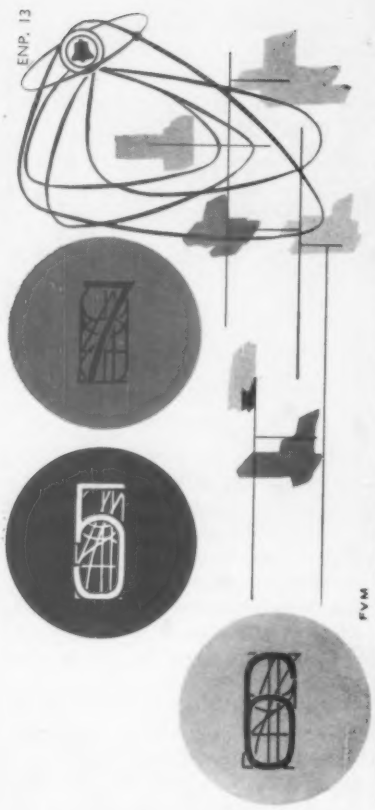
Among the characteristics of the book that I noted are the extensive use of integral-equations for neutron processes rather than differential equivalents; the emphasis on establishing limits of validity for working methods such as age theory; the frequent appearance of useful series approximations; and the tendency to abbreviate derivations in the interest of more thorough subject coverage.

Several topics that are given fuller treatment than in most books are flux distributions in various elaborations of the simple cell, variational development of minimum critical mass, age-diffusion behavior, fuel-consumption and fission-product kinetics, the finite-difference multigroup theory and P_3 spherical-harmonics solutions for cylindrical geometry. Of particular value are reproductions of Russian logic on the theory of resonance-escape probability for heterogeneous reactors leading to the $(S/M)^{1/2}$ dependence and the equivalent of the small-source theory of finite lattices. For these reasons, and because of the novelty and ingenuity displayed in the treatment of many small points, the book should make a useful reference for reactor physicists or designers.

Some of the book's defects are readily admitted by the author. Very little material on light-water systems is given and the control-elements discussion is too brief. Also a modern advanced text should deal with nonuniform systems, thermalization and preparation of group constants. A more basic weakness, which I have seen in similar books, is the failure to give body to the theory through numerical examples based on specific reactor systems. In this sense Galanin's work more closely resembles Glasstone and Edlund or Weinberg and Wigner than books by Meghreblian and Holmes or myself.

As a text, Galanin's book suffers from a lack of details in derivation and a separation from reality of reactor-physics situations. Only with considerable augmentation by the lecturer and ample problem assignments could it serve more than a supplementary reference.

Finally, the scope and depth of understanding that is displayed by this work should be a reminder that Americans must not delude themselves into ascribing any lack of competence to scientists in the Soviet Union.



ELECTRONICS FOR NUCLEONICS

SCALER CHRONOSCOPE

Bell Telephone scaler chronoscope gives you top quality reproduction of automatic counting and printing. It is so constructed that from a small stock of basic modules a wide scope of performances can be covered.
This type normally supplied in a metal case is also available for rack mounting

- preset time
- preset count
- result printing facilities
- interchangeable modules
- in line read out
- fully transistorized

Our staff is always available to answer your inquiries.

Bell Telephone Mfg Co

"Nuclear Energy division"
33, Berkenrodelei
HOBOKEN-Antwerp-BELGIUM

Both a
PROGRAMMER
guided by a pencil-drawn curve
NO CAMS
and a
RECORDING CONTROLLER
which superimposes a record of actual process performance and applies corrective control when performance deviates from the plotted program

PREKORDER TRADE-MARK

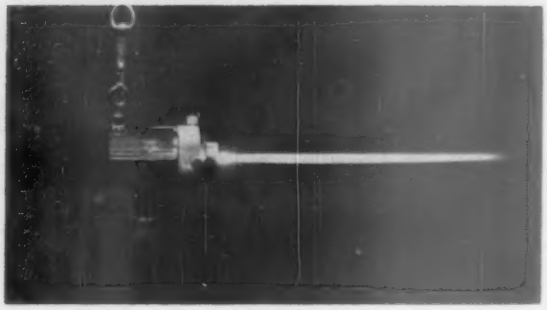
brings new flexibility to the automation of industrial process with closed-loop control.

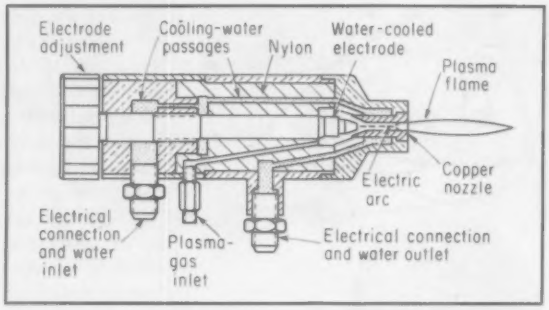
1. **Pencil Programming** — No cams to cut.
2. **Superimposed Recording** — PreKorder's permanent record of process performance on a program chart overlay permits continuous visual comparison of record and chart.
3. **Programmed Limits**—To trigger alarm or shut-down circuits in case of process malfunction, just pencil allowable operating limits on the recording chart.
4. **Programmed Gain**—Varying the space between pencilled program lines varies the proportional control band or system gain.

Typical PreKorder applications are in programming temperature, pressure, power, load, flow, position, and other process variables. Both round and strip-chart models are available.

RI RESEARCH INCORPORATED

P. O. Box 6164N,
Minneapolis 24, Minn.





Plasma Jet for Nuclear Research and Industry

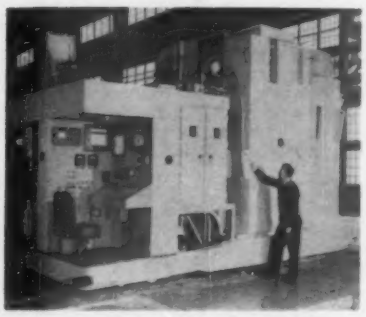
Out of the research in thermonucleonics are coming several useful instruments based on the controlled fusion approach but operating at temperatures far lower than the hundreds of millions of degrees necessary for controlled fusion. One of these practical instruments is the plasma jet that produces gas temperatures through arc heating in the 5,000–60,000°F range (as compared with 5,600°F for hydrocarbon-oxygen flame). Although these gases are not plasmas in the true sense of the word since they are usually only partially dissociated at these temperatures, they are still extremely useful for nuclear research and industry.

In addition to high-temperature environment experiments, the application of plasma jets to three particular fields is of particular interest to the nuclear industry: plasma-flame spraying, cutting nuclear metals and materials and producing many spherical particles.

Plasma-flame spraying. Because they resist wear, heat and corrosion, plasma-sprayed coatings are used in the nuclear field for refractory coatings to protect casting models, fuel elements and control rods. In plasma-flame spraying, powder is injected into the hot gas stream where it melts and is then caused to impinge on the surface to be covered. On the surface the droplets are flattened and bound to one another. Since the plasma can be generated from completely inert gases like argon and the entire gun operates in a controlled-atmosphere chamber, powdered materials like zircaloy-2 can be sprayed without oxidation or appreciable contamination of nitrogen or oxygen. After being sprayed on uranium-bearing fuel plates, 0.005–0.010-in. coatings of zircaloy-2 have passed accelerated 1-year corrosion tests. Thus this plasma spray process insures protection of the base material from hot, high-pressure water.

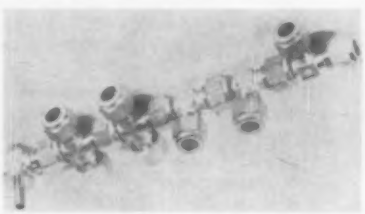
Cutting with plasmas. The quality of materials cut with the plasma jet is excellent; the pieces are ready for welding without additional surface preparations. Cutting speed for stainless steel and aluminum are 50 in./min for plate thicknesses from ¼ to 1½ in.

Making spherical particles. In the nuclear field atritted or chemically formed porous or angular particles must often be reprocessed into dense spherical balls. For example, spherical particles of UO_2 are needed for vibration-packing UO_2 in nuclear reactor fuel cans. A low-velocity, high-temperature plasma-gas stream will produce spherical particles more accurately than other methods—and at less expense.—Thermal Dynamics Corp., Lebanon, N. H.



Cask car for Fermi reactor. Heavily shielded, 200-ton car (above), complete with heat-transfer system, replaces spent fuel elements in a reactor with fresh ones and removes radioactive wastes safely over 100 ft of railroad track to storage areas outside the reactor building.—Baldwin-Lima-Hamilton Corp., Eddystone, Pa.

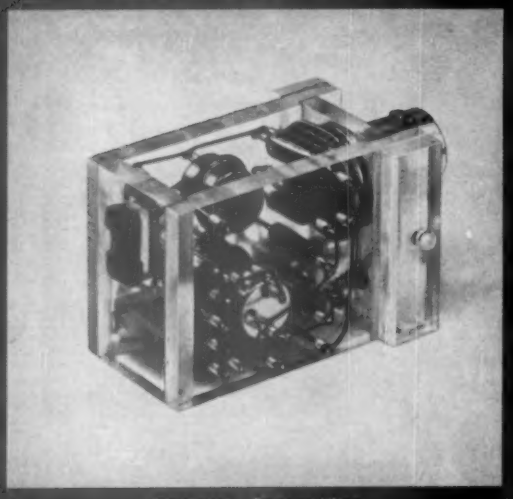
Air sampler. Model CF-750A meets the more rigid AEC exposure-limit radiation requirements with its automatic constant-flow control that eliminates operator supervision needed for manual air-sampling devices. This compact unit (½ ft³) has a accuracy of ±2%, constant flow rates from 3 to 6 cfm and grab sampling of ~20 cfm for short periods.—Filtronics Inc., P. O. Box 200, Cowell, Calif.



Adapter fittings. Swagelok adapter tees, elbows and crosses (above) come in sizes from ⅛ to 1 in. in machineable metals and plastics. Connections made with the fittings are leakproof and space saving; tees and elbows can be perfectly aligned in the direction of tubing runs.—Crawford Fitting Co., 884 E. 140 St., Cleveland 10, O.

Research LINAC

Radiation Handler—Mobot® Mark II



Detector—Preamplifier

Opportunities in basic research or development engineering in our expanding

nuclear electronics laboratory

programs: Operating in a radiation environment is a many faceted problem that offers challenge and growth to many kinds of engineers and scientists in our Nuclear Electronics Laboratory. They are contributing to such projects as: simulating radiation environment to study the radiation resistance of electronic components and systems; the design of LINACS, producing either electron beams, gamma rays or neutron pulses, uniquely adapted to current needs in radiation research, effects testing, medical therapy, sterilization, industrial processing and radiography; radiation detection and measurement with such devices as the Hughes charged particle detector; and mobile remote handling equipment, such as the MOBOT®.

facilities: The laboratory's research and test facilities include a 1 Mev beam generator, an underground LINAC installation and a 500-curie cobalt radiator. An improved 10 Mev LINAC is being constructed. The unexcelled facilities of the Hughes Aircraft Company, which include 5 million square feet of research development and manufacturing area, support the technical competence of a staff which is a demonstrated leader in electronic system and component development.

openings: **Physicists, Electronic Engineers and Mechanical Engineers to participate in the development of High Power Particle Acceleration, Solid State Radiation Detectors and associated data processing equipment or mobile remote handling systems.**

If you are a graduate electronic engineer, physicist, mechanical engineer or metallurgist and have experience which is applicable to the above programs, please airmail your resume to:

Mr. Robert A. Martin, Supervisor, Scientific Employment, Hughes Aerospace Engineering Division, 11940 W. Jefferson Blvd., Culver City 53, California.

WE PROMISE YOU A REPLY WITHIN ONE WEEK

At Hughes, all qualified applicants will receive consideration for employment without regard to race, creed, color or national origin.

Creating a new world with Electronics

HUGHES

HUGHES AIRCRAFT COMPANY
AEROSPACE ENGINEERING DIVISION

DEPENDABILITY
IN
RADIOCHEMICALS

Processing laboratories at Amersham.

Over 100 Compounds Labelled with Sulphur–35

These are prepared by the Radiochemical Centre to exceptionally high standards of quality. Typical labelled chemical intermediates, analytical reagents, biological compounds and drugs include:

Chemical Intermediates	chlorosulphonic acid hydrogen sulphide sulphur dioxide
Analytical Reagents	dichloroethyl sulphide (mustard gas) phenyl *iso*-thiocyanate *p*-iodobenzenesulphonyl chloride ('Pipsyl chloride')
Biological Compounds	DL-cystine DL-methionine
Drugs	chlorpromazine 6-mercaptopurine phenothiazine

Many sulphur compounds such as the above are available from stock, others at short notice. A much fuller list is given in our catalogue 'Radioactive Chemicals', and we are always ready to consider the synthesis of other compounds to individual requirements.

Comprehensive catalogues are available on application.

Enquiries for all radioactive supplies and services to:—

THE RADIOCHEMICAL CENTRE

Amersham, Buckinghamshire, England

World centre for DEPENDABLE RADIOCHEMICALS

Telephone: Little Chalfont 2701 *Cables: Activity, Amersham, Telex*
Telex: Active, Amersham 83141

TAS/RC.72

Steel for Argonne synchrotron. 5,000 tons of steel reinforcing bars (above) give added strength to concrete walls of 210-ft-diameter Argonne synchrotron.—U. S. Steel, 525 William Penn Pl., Pittsburgh 30, Pa.

Laboratory radiation kit. For colleges and research labs Nuclab II offers a RCR-2 Scaler Ratemeter—a compact instrument containing a 2-decade scaler, multirange ratemeter, elapsed timer, 4-digit register, 1,500-volt supply and loudspeaker. Also included are 2 G-M detectors, sample holder, absorbers, radioactive sources, planchets, instruction manual and carrying case.—Nucleonic Corp. of America, 196 Degraw St., Brooklyn 31, N. Y.

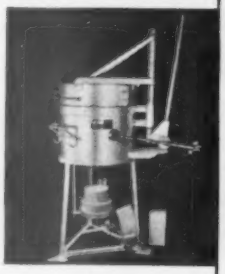
Manipulators. Three Columbus Die Tool manipulators are now installed in hot cell in Hanford's radiometallurgical laboratory. During tests on radioactive metals, manipulators handle fuel elements and reactor parts.—Columbus Die, Tool and Machine Co., Columbus, O.

Remote control unit. Mechanical remote control (above) for changing output speeds consists of a flexible shaft and an indicator handwheel with read-

Zircoa
HOT POT LAB FURNACE

...meets all your requirements to 4600°F.

EASY TO MAINTAIN
•
RUGGED
•
QUIET
•
SIMPLE TO OPERATE
•
LOW HEAT LOSS



You'll find many uses for the Zircoa Hot Pot Furnace, including load bearing tests, melting point determinations, high purity melts, and sintering of high temperature materials.

Burners can be supplied for the use of oxygen with acetylene, propane or natural gas. Complete with necessary manifolds, gauges, etc., ready to operate. Heat shield, muffles, crucibles, setters and other accessories are available from stock.

As low as $1520. Write for descriptive bulletins.

Zircoa
31501 SOLON ROAD, CLEVELAND 39, OHIO

ZIRCONIUM CORPORATION OF AMERICA

ARAPAHOE
TRADE-MARK

SCINTILLATION PHOSPHORS

"POPOP" (Scintillation Grade)
Fluorescence Max. 4200A

2,5-DIPHENYLOXAZOLE (Scintillation Grade)
Fluorescence Max. 3800A

ALPHANAPHTHYLPHENYLOXAZOLE (Scintillation Grade)
Fluorescence Max. 4050A

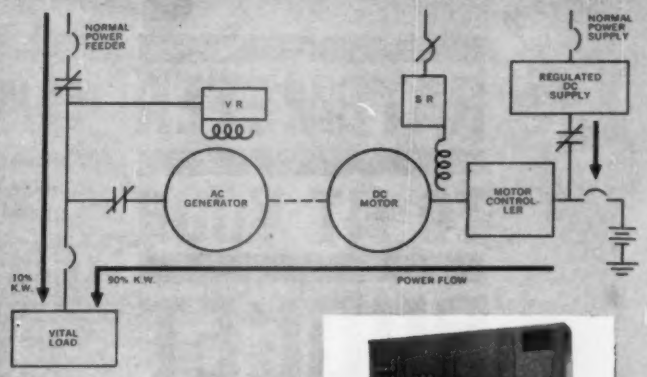
p-TERPHENYL (Scintillation Grade)
Fluorescence Max. 3460A

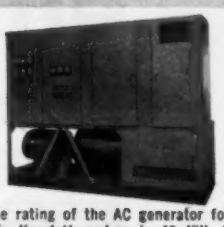
1,1,4,4,-TETRAPHENYLBUTADIENE (Scintillation Grade)
Fluorescence Max. 4320A

CADMIUM PROPIONATE, Anhydrous
Solubility, 12g per 100 ml. of 1:9 methanol-toluene

Available from stock . . . write to Dept. "K" for free booklet on these products.

ARAPAHOE CHEMICALS, INC.
[illegible] BOULDER, COLORADO
PRODUCERS OF FINE ORGANIC CHEMICALS





The rating of the AC generator for this Kearfott system is 40 KW, 3 phase, 60 cycle, 460 volts.

CONTINUOUS UNVARYING POWER FOR VITAL INSTRUMENTATION IN CHEMICAL PROCESSING

A TYPICAL APPLICATION OF KEARFOTT UNINTERRUPTED POWER SYSTEMS

In chemical processes where even a split-second interruption of computers and related instruments can cause heavy losses, protection against power failure pays high dividends on a relatively modest investment. Take, for example, the Kearfott system pictured here, which assures surge-free entrance of emergency power in zero time in case the normal input varies or fails.

In normal operation, the DC motor runs continuously on power from the static supply, which also keeps the batteries fully charged at all times. The AC generator operates in parallel with the main power and furnishes about 90% of the vital load requirement.

If the main power fails, the DC motor continues to run, drawing its current from the batteries. Simultaneously, the AC generator assumes 100% of the vital load. When main power is restored, the system automatically reverts to normal operation.

Kearfott systems are available with generator ratings to 150 KVA 60 and 400 cycles, single and polyphase, and provide frequency, voltage and transfer regulation as required by the application.

Write for complete data

GP

KEARFOTT DIVISION
GENERAL PRECISION, INC.

Little Falls, New Jersey

a RATEMETER TO FIT YOUR BUDGET from LIONEL*

$175 F.O.B. Brooklyn Plant Price Includes Probe and Detector

The new transistorized Type 457 radioactivity ratemeter will fit the most modest school or university budget and will fill your radiological counting needs with years of accurate trouble-free service.

- Transistorized—No warm-up time.
- Adjustable Power Supply (500 V to 1200 V).
- Large 4½ inch meter face indicates count rate . . . has dual range: 0-1500 CPM; 0-15,000 CPM.
- Loudspeaker for aural monitoring with volume control.
- Neon flasher for visual monitoring.
- External jack for meters or recorders for demonstrations, etc.
- The Anton/Lionel 114/6993 thin-wall, stainless steel halogen quenched counter tube will withstand the most severe laboratory or student abuse. Its life is unaffected by extended operation and it cannot be damaged by overvoltage.
- The Type 457 was designed to perform all experiments and demonstrations such as those listed in
- "Teaching with Radioisotopes prepared by the U.S. Atomic Energy Commission."

LIONEL ELECTRONIC LABORATORIES Division of the Lionel Corporation

*FORMERLY ANTON ELECTRONIC LABORATORIES, INC. / 1226 FLUSHING AVE., B'KLYN 37, N. Y.

ing dial. 5-ft anti-backlash flexible shaft allows all handwheel movements to be transmitted without shaft absorption.—Reliance Electric and Engineering Co., Cleveland 17, O.

Decade scaler. For use with automatic sample changers Model DS-1AP can register 10^6 cpm with counting periods up to 55 min preset in the automatic timer.—Nuclear Measurements Corp., 2460 N. Arlington Ave., Indianapolis 18, Ind.

Radiation emergency kit (above) contains materials necessary to handle adequately minor radiation emergencies and to contain major emergencies. It includes acid suit, plastic shoe covers, plastic gloves, facemask, G-M tube, ratemeter, dosimeter, charger, radiation rope, containers for water, Phisohex, hand brush, absorbent swabs, cotton buds, first-aid kit and handbooks.—Nuclear Engineering Co., Inc., 65 Ray St., Pleasanton, Calif.

Gage pressure transducer. Tiny Model 100 can be used for pressure measurements in small spaces under severe environments. Because these Series SP2 transducers are highly stable under gamma radiation, they can be used to monitor reactor-coolant water pressure.—Standard Controls Inc., 1130 Poplar Pl., Seattle 44, Wash.

Pyrometer. Model 600 panel-mounted electronic pyrometer measures and controls temperatures at distances up to 10,000 ft. The transistor pyrometer operates on signals from thermocouples;

May we introduce . . .

Our newest **SCINTILLATION PHOSPHORS**

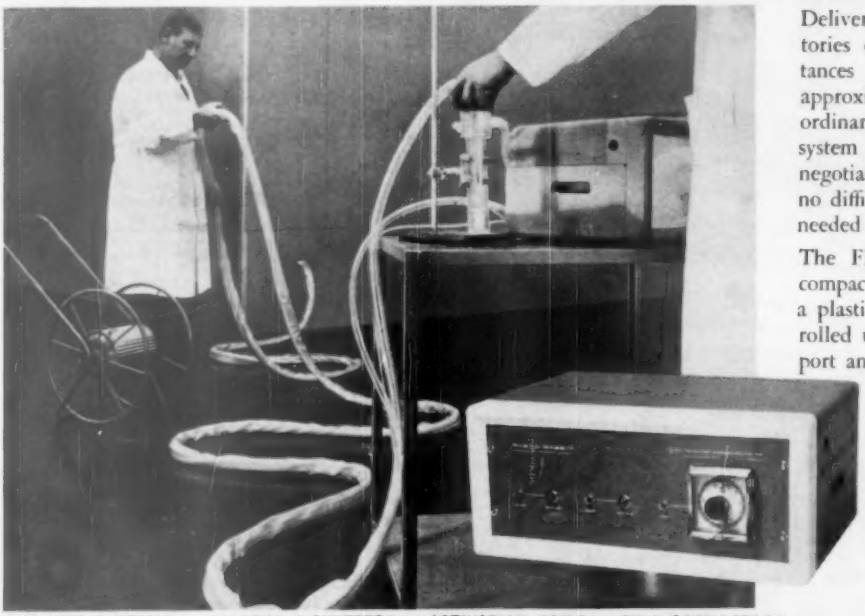
- **Thermal Neutron Detector NE421**
  Enriched 96% Lithium-6 in this detector provides high detection efficiency combined with excellent discrimination against gamma radiation.
- **High Temperature Plastic Phosphor NE160**
  For measurement at temperatures over 100°C.
- **High Flash Point Scintillators**
  For safe, economical, giant liquid scintillator installations.
- **Liquid and Plastic Scintillators**
  For the challenging technique of Pulse Shape Discrimination.
- **Scintillating Vials NE814**
  For convenient counting of aqueous samples.
- **Scinstant Scintillators**
  Premixed solute combinations for convenient dependable preparation of liquid scintillators for internal counting.

550 BERRY STREET
WINNIPEG 21, CANADA

Associate Co:
Nuclear Enterprises (G.B.) Ltd.
Edinburgh, Scotland

NUCLEAR ENTERPRISES LTD.

DIFFICULT SAMPLE TRANSFERS TO *ANY* LOCATION MADE EASY WITH NEW FLEXO-RABBIT SYSTEM



Deliver irradiated samples to laboratories or counting systems over distances up to 100 feet in length in approximately one second. The extraordinary flexibility of the all plastic system allows the sample container to negotiate four inch radius curves with no difficulty. The only pressure source needed is a standard gas cylinder.

The FLEXO-RABBIT consists of a compact, light-weight control unit and a plastic tubing system which may be rolled up on a mobile reel for transport and storage.

Typical applications:

REACTORS • PULSED SOURCES
LINACS • HOT CELLS
CYCLOTRONS • COBALT SOURCES
UNDERWATER SOURCES
VAN DE GRAAFFS
COCKCROFT WALTON ACCELERATORS
RADIOGRAPHIC EQUIPMENT

$2750.00 COMPLETE

TRANSFER SYSTEMS • NEUTRON HOWITZERS • ACTIVATION FOILS • PILE OSCILLATORS

Reactor Experiments, Inc., 140 Harbor Blvd., Belmont, Calif.

R/Ex

new vibrating reed electrometer

The Vibrating Reed Electrometer Type N616 measures very small direct currents and voltages with high zero stability. Applied D.C. is converted to A.C. by a vibrating reed capacitor and amplified by a stable A.C. amplifier. The output is rectified and measured on a 5" (13 cm) panel meter calibrated to indicate the D.C. voltage at the input.

Head Unit

For full information on the N616 Electrometer or on any of the wide range of Ekco Equipment used in research, medicine, aviation and industry in more than 80 countries—write to

EKCO *Electronics Ltd.*

Southend-on-Sea, England.

In U.S.A., contact associate company:

American Tradair Corporation, 34-01 30th Street, Long Island City 6, New York

no zero adjustment is needed before operation. A single-pointer panel meter indicates temperatures. When temperatures must also be controlled, meter uses a locking-contact meter-relay with contacts mounted on additional pointers.—Metronix, Inc., Chesterland, Ohio.

LITERATURE AVAILABLE

Radiation Instruments Catalog. 50 pp.; Nuclear Instruments & Accessories Inc., 150 Fifth Ave., New York 10, N. Y.

Radiation Polymerization Dosimeter. 3 pp.; Radipol Dosimeter-Marion Laboratories, Inc., Kansas City, Missouri

Plutonium-Beryllium Neutron Sources. 7 pp.; NUMEC, Apollo, Pa.

Nuclear Instruments and Systems. 40 pp.; Hamner Electronics, Co., Inc., P. O. Box 531, Princeton, N. J.

Vacuum Coating and Equipment. 27 pp.;
Vacuum Pumping Equipment. 15 pp.;
Vacuum Ion Pumps. 8 pp.; Consolidated Vacuum Corp., Rochester 3, N. Y.

Computer Format Recorder. 8 pp.; Epsco Systems, 275 Massachusetts Ave., Cambridge 39, Mass.

General Purpose Analog Computer. 20 pp.;
Handbook on Analog Computing. 70 pp.; Gaynor & Ducas, Inc., 400 Madison Ave., New York 17, N. Y.

New Solutions in the Science of Simulation. 18 pp.; Computer Systems, Inc., Culver Rd., Monmouth Junction, N. J.

Nuclear Engineers and Consultants to the Free World. 8 pp.;
Services in All Fields of Computer Application. 8 pp.; Internuclear Co., Clayton 5, Missouri

Just Published

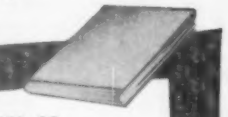
MATHEMATICAL HANDBOOK FOR SCIENTISTS AND ENGINEERS

Definitions, Theorems, and Formulas for Reference and Review

By GRANINO A. KORN
Professor of Electrical Engineering
University of Arizona
and THERESA M. KORN

Here is helpful reference to vital information in all areas of mathematics—definitions, theorems, formulas . . . and an outline of mathematical methods essential in today's science and engineering applications. Each of the book's 21 authoritative chapters provides rapid review of an entire mathematical subject. Topics covered include vector analysis, Laplace transforms, Boolean algebra, random processes, calculus, finite-difference methods, numerical computations, and more.

Illustrations, tables, and boxed groups of related data highlight a full range of facts and methods—from real numbers and curvilinear coordinates . . . to differential geometry, statistics, and special functions. This Handbook brings you a ready means for answering virtually any mathematical question likely to arise in your day-to-day work. 943 pp., 110 tables, $20.00 (payable $5 in 10 days and $5 monthly).



CONTROL OF NUCLEAR REACTORS AND POWER PLANTS

Just Published—Second Edition. Provides latest data on the use of servomechanism techniques for the control of nuclear power plants. Covers basic control problems of all types of reactors—from homogeneous to boiling reactors. Includes information on delay fractions for fuels other than U-235, and for neutron spectra other than thermal. By M. A. Schultz, Westinghouse Testing Reactor. 2nd Ed. 466 pp., illus., $12.50

HANDBOOK OF CHEMISTRY

Just Published—Tenth Edition. A vast compilation of facts, data, tabular material, and experimental findings treating every aspect of chemistry. This revised edition lists 6500 organic compounds with their physical constants—chemical and physical properties of classified substances—tables of specific properties, and more. Edited by N. A. Lange, Reg. Prof. Engr. Asst. by G. M. Forker, Gen. Elec. Co. 10th Ed. 1969 pp., $11.00

FREE EXAMINATION

McGraw-Hill Book Co., Dept. FNU-6
327 W. 41st St., New York 36, N. Y.

Send me book(s) checked below for 10 days' examination on approval. In 10 days I will remit for book(s) I keep plus few cents for delivery costs, and return unwanted book(s) postpaid. (We pay delivery costs if you remit with this coupon—same return privilege.)

☐ Korn & Korn—Math. Hdbk. for Scien. & Engr., $20.00 ($5.00 in 10 days; $5.00 monthly)
☐ Schultz—Con. of Nuc. Reac. & Power Plants, $12.50
☐ Lange—Hdbk. of Chemistry, $11.00

(PRINT)
Name .....
Address .....
City ..... Zone ..... State .....
Company .....
Position .....

For price and terms outside U.S. write McGraw-Hill Int'l., N.Y.C. FNU-6

Galaxy cluster in Coma Berenices
Mount Palomar Observatory

Neutron-proton collision in a cloud chamber
Brookhaven National Laboratory

RCA PHOTOMULTIPLIERS PERCEIVE THE IMPERCEPTIBLE

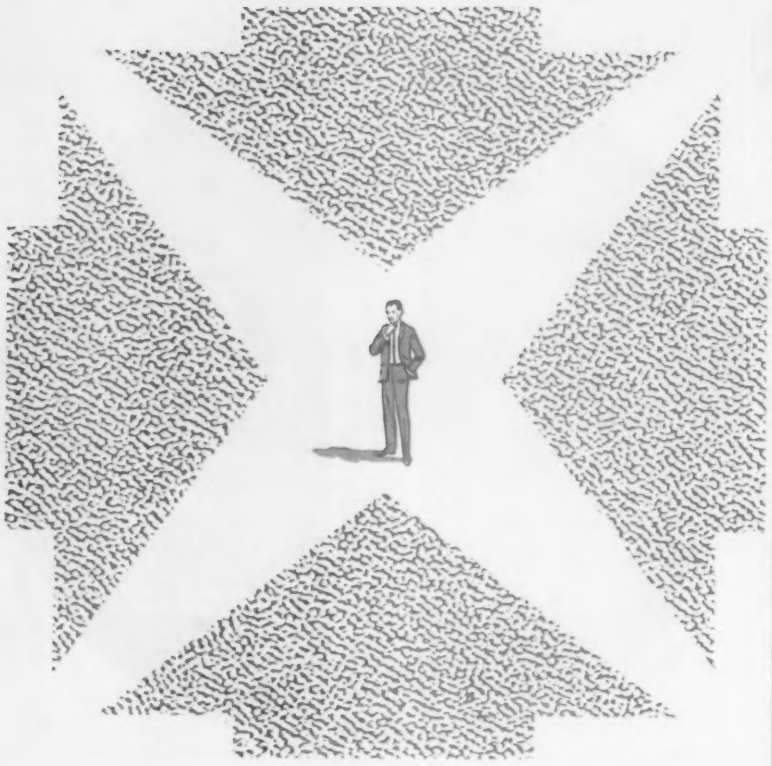
RCA multiplier phototubes have made significant contributions toward our understanding of both macrocosm and microcosm. Their tremendous current amplification (up to 86,000,000 in one type), their extreme photosensitivity, high-frequency response and excellent linearity have made possible many of today's most sophisticated scientific measurements.

TYPICAL MULTIPLIER PHOTOTUBE APPLICATIONS:

- *Detection and measurement of extremely low levels of light, ultra-violet, near infrared, nuclear radiation, and X-rays*
- *Scintillation counting*
- *Automatic X-ray exposure controls*
- *Startracking of distant galaxies*
- *Light-actuated relays and other light controls*
- *Facsimile transmission*
- *Critical thickness measurements of metals and plastics*

For a copy of technical catalog CRPD-105B describing RCA multiplier phototubes and other photosensitive devices, see your Authorized RCA Industrial Tube Distributor or send 50 cents with your request to: Commercial Engineering, RCA Electron Tube Division, Harrison, N. J.

The Most Trusted Name in Television
RADIO CORPORATION OF AMERICA



Are your nuclear advisors hampered by ties to equipment manufacturers?

Regardless of the nature of a nuclear energy project, its successful accomplishment requires competence, dedication, *and complete objectivity*. Internuclear Company—staffed by *independent* specialists whose talents are not confined by a parent organization manufacturing nuclear equipment—is uniquely qualified to provide this impartiality for your engineering, design, or consulting requirements.

The wisdom of choosing Internuclear's unbiased viewpoint has been proved on many important assignments throughout the free world . . . for such clients as the United States Atomic Energy Commission, Danish Atomic Energy Commission, Italy's Societa Elettronucleare Nazionale, Nuclenor, the Japanese Atomic Energy Research Institute, Allis-Chalmers, Babcock and Wilcox, General Electric, General Motors, Phillips Petroleum, and Westinghouse.

Internuclear assistance is available for limited assignments in specified areas or for entire programs. Complete consulting and engineering services in all fields of computer application are also offered. Write for brochure.

nuclear engineers and consultants to the free world

internuclear company
A SUBSIDIARY OF PETROLITE CORPORATION

HEADQUARTERS
7 N. Brentwood Blvd.
Clayton 5,
Missouri
PArkview 7-2668
Cable: INTERNUC

Representative: 1625 Eye Street, N. W., Washington 6, D. C., MEtropolitan 8-1253

INDUSTRY NOTES

● AEC's raw-materials program has undergone organizational and personnel changes. The Division of Raw Materials, formerly divided into domestic and foreign sections under assistant directors, has been consolidated under Thomas B. Upchurch, Assistant Director for Procurement. Reporting to Upchurch will be Charles W. Tully, Chief of Foreign Procurement Branch, and Richard H. Kennedy, Chief of Domestic Procurement Branch.

● General Electric is planning to construct a $100,000 facility to test internal steam separation systems at its Atomic Power Equipment Department headquarters in San Jose, Calif. The facility, scheduled to begin operation in November, will test ways to optimize design of internal steam separation equipment and will help determine minimum length and diameter required for reactor vessels. Steam separators and reactor vessels are two of the costliest reactor components.

NEW BUSINESS: For the third successive year, **Tracerlab** has received a contract ($34,000 this year) from General Services Administration to supply nuclear calibrators to the Office of Civil and Defense Mobilization. . . . Phillips Petroleum's Atomic Energy div. has awarded a contract to **Sylcor div.,** Sylvania Electric Products Inc., for production of more than 1,000 elements and control rods for two reactors (ETR and MTR) at the National Reactor Testing Station in Idaho. . . . **General Electric's** Atomic Power Equipment Department will furnish the nuclear instrumentation and safety system for the recently-completed $15-million Plutonium Recycle Critical Facility at Hanford. . . . AEC has signed an $18.5-million uranium-procurement contract, effective April 1, 1961, with the **Vanadium Corporation of America.**

FINANCIAL: **Varian Associates** has filed with SEC for registration of 347,883 additional shares of stock to be offered on a one-new-share-for-ten-old-shares basis. The proceeds will be used for construction of new buildings at the Palo Alto, Calif., headquarters and for a new plant at Lexington, Ky.

WHERE TO BUY

Featuring additional products, specialties and services for Atomic Power, Nuclear Engineering and Applied Radiation.

TRITIATED TITANIUM FOIL
as beam target in neutron generators, ion producer (gas chromatography, static eliminators, vacuum gauges ionization tubes). Tritium content: approximately 1 curie/in.² (or to requirements). Backing: 2 mil stainless . . . other metals and thicknesses available on special order. Also DEUTERATED TARGETS. ADDRESS INQUIRIES TO

RADIATION RESEARCH CORPORATION
1150 Shames Drive
Westbury Industrial Park, Westbury, N.Y.
"First in Nuclear Batteries"

NEUTRON Shielding Windows

Announcing: Gadolinium glass originated by Penberthy. Gadolinium glass permits direct viewing with mixed neutron and gamma radiation.

PENBERTHY INSTRUMENT CO.
6701 Maynard Ave., Seattle 8, Wash.
PArkway 5-5400

PROFESSIONAL SERVICES

ASTRA, INC.
Consultants For Industry & Government
Nuclear: Nuclear Analysis, Reactor Specifications & Design, Shielding, Health Physics, Criticality Hazards Studies
Space: Radiation Effects, Propulsion, Satellite Power Plants, Planetary Simulators
Advanced Technology: Heat Transfer, Stress Aanalysis, Thermodynamics, Electronic Data Processing, Cryogenics
Raleigh N. C. VAnce 8-4386 Cable: "ASTRA"

SEARCHLIGHT SECTION

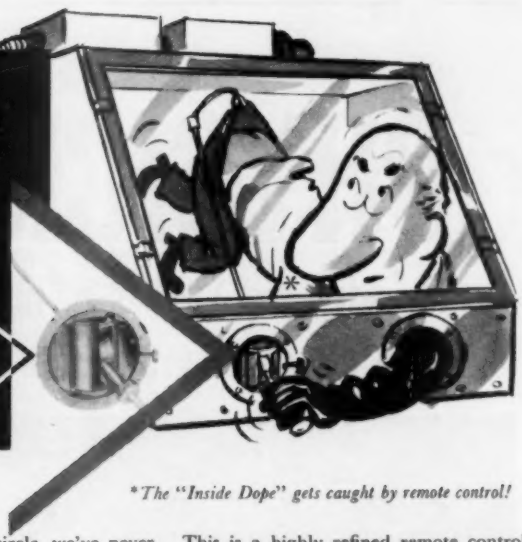
(Classified Advertising)

FOR SALE

For Sale: 1952–53 Nucleonics Magazine. 1960–61 Electronics Magazine. FS-6734 Nucleonics, 645 N. Michigan Ave., Chic. 11, Ill.

Let's give the Little Man a BIG HAND

(SERVO TURRET REMOTE CONTROL TONG MANIPULATOR)



**The "Inside Dope" gets caught by remote control!*

If this isn't a vicious circle, we've never seen one! "Dopey's" trying to demonstrate that K.S.E.'s Servo Turret Remote Control Tong Manipulator operates like a right hand. Its precise, peripheral action permits the operator to safely perform any desired maneuver inside a Safety Enclosure.

This is a highly refined remote control tong manipulator, noted for its extreme ease of handling. The complete assembly affords more than 2" of shielding and is normally used with a lead cave or remote control enclosure for the safe handling of radioisotopes.

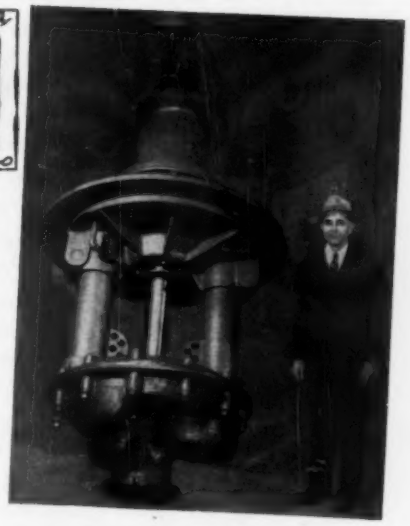
For complete information, call or write

K·S·E KEWAUNEE SCIENTIFIC EQUIPMENT ADRIAN, MICHIGAN

4042 Logan Street

WANTED!

PUMPING JOBS NOBODY ELSE WANTS!



Nagle pumps are giving excellent service handling radioactive wastes and slurries. Casings and impellers are designed for extended service in exposure to abrasive, corrosive and molten fluids. Pumps feature specialized design to minimize and frequently eliminate maintenance and breakdown.

The 10" Type "SWO-X" Pump shown, built for the Oak Ridge Atomic Energy facility, has no bearings below the floor plate (no bearings in or near material being pumped), no rubbing contact between stationary and moving parts below the radial bearing. Bottom entrance eliminates troubles from materials congealing or settling-out inside casing when pump is idle.

Nagle has had broad experience in designing horizontal and vertical centrifugal pumps for nucleonic applications. Send for data.

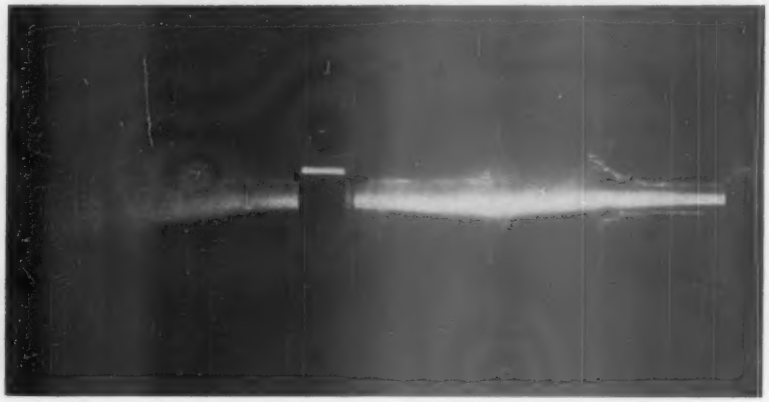
Tough jobs call for

Nagle PUMPS
FOR ABUSIVE APPLICATIONS EXCLUSIVELY

Nagle Pumps, Inc.
1242 Center Ave., Chicago Heights, Illinois
Representatives in Principal Cities

PHYSICISTS

for advanced studies of high-performance electrical propulsion systems...



Great interest has been aroused by our unusual oscillating-electron ion engine which produces a high-velocity, electrically-neutral plasma beam. Since this electrically-neutral stream eliminates the space-charge effect, there is no theoretical limit to the thrust capability of the device. ● Past successes and current progress with this device, (and in other areas of plasma research) now require a material expansion in this entire effort. As a result, a number of very attractive Senior Positions are being created for electrical propulsion specialists — particularly physicists with advanced degrees and experience. ● These positions should have particular appeal to those interested in studies of high-energy plasma sources, diagnostic techniques and other basic investigations that will lead to practical space propulsion devices. Included are both theoretical and experimental investigations of factors that determine plasma potentials, ionization and power efficiencies. ● This program is of the long-range sustained type with both corporate and government sponsorship. Superior facilities and assistance are available for numerical computation and experimental work. Publication of papers is encouraged as is close contact with related university research. ● Salary levels, benefits and the semi-academic approach will appeal to experienced men with demonstrated abilities.

You are invited to contact Mr. W. R. Walsh, Personnel Department

RESEARCH LABORATORIES
UNITED AIRCRAFT CORPORATION

400 Main Street, East Hartford 8, Conn.

All qualified applicants will receive consideration for employment without regard to race, creed, color or national origin.

NUCLEAR CALENDAR

International Atomic Energy Agency

August 3–11—Seminar on Physics of Fast and Intermediate Reactors, Vienna.
September 4–8—Conference on Plasma Physics and Controlled Nuclear Fusion Research, Salzburg, Austria.
September 11–15—Symposium on Treatment and Storage of High Level Radioactive Wastes, Vienna (probable). On all IAEA meetings, contact IAEA, 11 Kärntnerring, Vienna 1, Austria.

July 10–21—Course on Nuclear Energy for Senior Technical Executives in OEEC countries, sponsored by European Nuclear Energy Agency, Harwell Reactor School, Berkshire, U. K. Contact: OEEC, European Nuclear Energy Agency, 38, Boulevard Suceta, Paris 16e, France.

July 17–21—Gordon Research Conference on Radiation Chemistry, New Hampton, N. H. Contact W. George Parks, Director, Univ. of Rhode Island, Kingston, R. I.

July 31–Aug. 12—Joint IAEA-UN Economic Commission for Latin America seminar on electric power, including sessions on nuclear power, Mexico City, Mexico. Contact UN Economic Commission for Latin America, Ave. Providencia 871, Santiago, Chile.

August 6–26—Nuclear Physics Summer Course, sponsored by the Italian Physical Society, Varenna, Italy. Contact G. Polvani, Via Saldini 50, Milan, Italy.

August 28–30—Symposium on University Use of Subcritical Assemblies, jointly sponsored by ANS, ORNL, AEC; Gatlinburg, Tenn. Contact Symposium Office, University Relations div., Oak Ridge Institute of Nuclear Studies, Oak Ridge, Tenn.

September 5–12—2nd International Conference on High Energy Accelerators and Instrumentation, sponsored by the Commission on High Energy Physics of the International Union for Pure and Applied Sciences, Brookhaven National Lab., Upton, N. Y. Contact Prof. P. Fleury, Institut d'Optique, 3, Blvd. Pasteur, Paris.

September 6–8—Nuclear Instrumentation Symposium sponsored jointly by ISA, AIEE, IRE; North Carolina State College, Raleigh, N. C. Contact ISA Meetings Manager, Penn Sheraton Hotel, 530 William Penn Place, Pittsburgh 19, Pa.

September 6–9—Meeting of the American Physical Society, Seattle, Wash. Contact W. A. Nierenberg, Univ. of California, Berkeley 4, Calif.

EMPLOYMENT OPPORTUNITIES

The advertisements in this section include all employment opportunities—executive, management, technical, selling, office, skilled, manual, etc.

— RATES —

DISPLAYED: The advertising rate is $25.33 per inch for all advertising appearing on other than a contract basis. Contract rates quoted on request.
An advertising inch is measured ⅞" vertically on a column—3 columns—30 inches to a page.
Subject to Agency Commission.
UNDISPLAYED: $2.10 per line, minimum 3 lines. To figure advance payment count 5 average words as a line.
Box numbers—count as 1 line.
Discount of 10% if full payment is made in advance for 4 consecutive insertions.
Not subject to Agency Commission.

This Editor Must Be Replaced!

If you are an **engineer** or **scientist** with **nuclear experience** in the areas of radiation and instrumentation, and would like to **write** about the exciting world of nucleonics . . . send a resume and salary requirements to: EDITOR

NUCLEONICS
330 WEST 42nd ST., NEW YORK 36, N.Y.

ADDRESS BOX NO. REPLIES TO: Box No. Classified Adv. Div. of this publication. Send to office nearest you.
NEW YORK 36: P. O. Box 12
CHICAGO 11: 645 N. Michigan Ave.
SAN FRANCISCO 11: 255 California St.

POSITION VACANT

Radiochemist, experienced. Fine opportunity for well-qualified man to manage new industrial hot lab, developing equipment & techniques for high precision radioisotope counting. Reply 1853 Nichols Canyon Road, Los Angeles, Calif.

SELLING OPPORTUNITY AVAILABLE

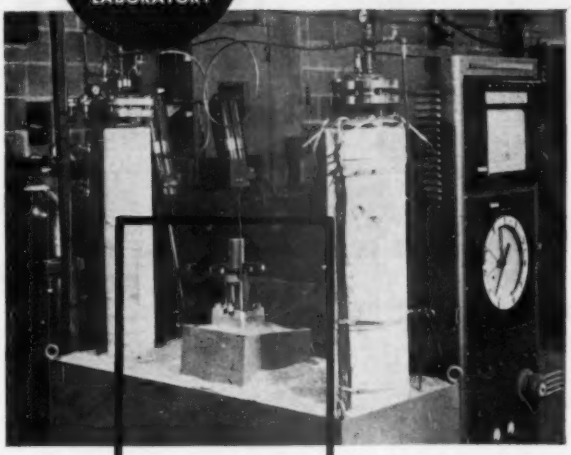
Nuclear equipment manufacturer and engineer specializing in irradiation and hot cell equipment, shipping containers and nuclear devices desires sales agents for open territories. Radiation Products, Inc., Ft. 40th Rd., Flushing, N. Y.

(Additional Employment Advertising on page 127)

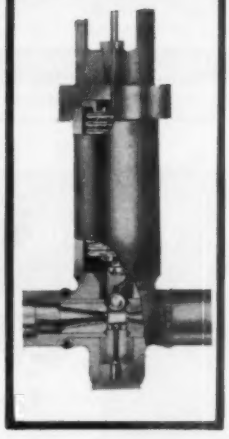
P-K Paul Venturi-Ball Valve Specified By

CASE HISTORY
ARGONNE NATIONAL LABORATORY

ARGONNE NATIONAL LABORATORY



P-K Paul Liquid Metal Valve in test loop under maximum temperature and pressure conditions at Argonne National Laboratory test site.



4" 1500 lb. Manually Operated Barstock Valve of 316SS, Stellited trim, with Bellows Seal and Extended Bonnet.

FOR 1600°F LIQUID SODIUM SERVICE

A year and a half ago Argonne National Laboratory selected a stock P-K Paul Liquid Metal Valve for testing and evaluation. Experience gained in testing this valve led to the purchase of five additional valves of this type for use in the TREAT "In-Pile Sodium Loop". Their use for this difficult service — tight shut-off of liquid sodium at operating temperatures above 1000°F — **illustrates again the superior performance of the unique Venturi-ball design.**

The P-K Paul Valve offers high flow capacity, wide rangeability, straight through non-turbulent flow, low operating thrust, self-purging characteristics, high resistance to erosion, abrasion and corrosion, and, most important in this application, positive shut-off.

For specification and application information on the complete line of P-K Paul Valves, write today for General Catalogue GV101.

General Kinetics Corporation
197 South Van Brunt Street • Englewood, New Jersey

FOR DEPENDABLE PROTECTION
IN CRITICAL OPERATIONS

CHARCO
DRY BOX
GLOVES

PREMIUM QUALITY
MILLED NEOPRENE

FLEXIBLE, FINGER SENSITIVE AND COMFORTABLE
EACH DRY BOX GLOVE IS HIGH VOLTAGE TESTED

CHARCO NEO SOL ®

CHARCO RAD BAR ®

PREMIUM QUALITY, ALL MILLED NEOPRENE. THESE GLOVES ARE OIL, CHEMICAL AND OZONE RESISTANT. THEY CONFORM TO REQUIREMENTS OF ARGONNE NATIONAL LABORATORY SPECIFICATIONS PF-1-b-(Rev. 6).

SEAMLESS, LEAD-LOADED, MILLED NEOPRENE ARE OF A DENSITY OF 3.95 GRAMS PER CUBIC CENTIMETER. UNDER ACTUAL TESTS THESE GLOVES HAVE BEEN PROVEN TO SHIELD OUT SOFT GAMMA RAYS MORE THAN 85%.

WRITE FOR BROCHURE AND TECHNICAL DATA

Our Research and Testing Laboratories Welcome
The Opportunity To Help Solve Your Problems.

CHARLESTON RUBBER COMPANY

7 STARK INDUSTRIAL PARK — CHARLESTON, SOUTH CAROLINA

ALUMINUM NUCLEAR STORAGE RACK

by CPC

Engineered, machined and fabricated all aluminum nuclear spent fuel element storage rack designed by Stone and Webster, Boston, Mass. for Yankee Atomic Plant, Rowe, Mass.

QUALIFIED WELDERS

A.S.M.E. - National Boards
Aircraft - MIL-T-5021A
Navy - STD-248A
Code Inspection by Mutual Boiler and Machinery Insurance Company

WRITE FOR ALUMINUM BROADSIDE

CPC engineering

STURBRIDGE, MASS.

NEWSMAKERS

Roy B. Snapp has been appointed divisional vice president of American Machine and Foundry Co. in charge of its Washington office. Snapp has been with AMF since 1957; he previously served as secretary of AEC and as special assistant to AEC Chairman Lewis L. Strauss in 1953–54. Also at AMF, **Donald H. Weir,** formerly manager of nuclear equipment sales for the AMF Atomics div., has been appointed manager of the division's Nuclear Products Department with responsibility for manufacture, engineering, and sales of AMF Atomics nuclear products.

I. I. Rabi, Higgins Professor of Physics at Columbia University, has been elected to serve as president of Associated Universities, Inc., succeeding Leland J. Haworth who was recently appointed to membership on the Atomic Energy Commission. Rabi, a Nobel laureate in 1944, has been with Associated Universities since it was founded in 1946 and was a member of the Executive Committee of the Board from 1946 through 1959.

Jesse C. Johnson, director of the AEC Division of Raw Materials, received the third Ambrose Monell Medal for distinguished achievement in mineral technology. Johnson has been with AEC since 1948.

Seymour Rothchild has been elected president of New England Nuclear Corp., succeeding Dr. Edward Shapiro. Shapiro will devote his time to the Luminous Products div.

Lombard Squires, Manager of the Atomic Energy div. of E. I. du Pont de Nemours & Co., has been named chairman of the 1962 Nuclear Congress and Atomic Exposition. The event, to be held at the New York Coliseum, will summarize the progress of the nuclear industry during the early 1960's.

Paul Kruger has joined Hazleton-Nuclear Science Corp. as manager of the Nuclear Products Department in charge of research-development programs in radiochemistry, reactor technology, and industrial utilization of radioisotopes. He previously served in a similar capacity with Nuclear Science and Engineering Corp.—the eastern affiliate of H-NS.

THE KNOLLS ATOMIC POWER LABORATORY

...Where Achievements in Research Are Applied Today... And Developed Into Tomorrow's Nuclear Systems...

Selective program expansion—and commencement of applied research and development projects in new and promising areas of nuclear reactor and power plant technology—have generated several new openings of unusual potential at KAPL.

Positions are immediately available in:

Electrical Systems Design/Instrumentation and Control Equipment/Control Drive Electrical Design/ Physical and Process Metallurgy/Welding Engineering/Materials Design Analysis/Experimental Physics (PhD)/Theoretical Physics (PhD)/Nuclear Engineering/Statistical Design and Analysis/Programming

Forward your resume in confidence to Mr. F. W. Snell, Dept. 48-MG.

U. S. Citizenship Required. All qualified applicants will receive consideration for employment without regard to race, creed, color or national origin.

Knolls Atomic Power Laboratory
OPERATED FOR A E C BY
GENERAL ELECTRIC
Schenectady, New York

ENVIRONMENTAL RESEARCH

Chemists, Biochemists, or Biophysicists for study of low levels of radioactivity in physical and biological environment. Experience in radiochemical analyses, analytical chemistry, or biological sampling techniques preferred.

ATOMIC ENERGY OF CANADA LIMITED

Chalk River, Ontario

Canada

for POSITIONS in the NUCLEAR FIELD...

WRITE US FIRST!
Use Our Application
No Resume Required

Our national coverage and technical experience in the nuclear field offers the maximum opportunity to achieve your goals.

Confidential Handling
Employer Pays Fee

Write: Arthur L. Krasnow

ATOMIC PERSONNEL, INC.
1518 Walnut St. • Phila. 2, Pa. • PE 5-4908
An Employment Agency for the Nuclear Field

RADIOISOTOPE SERVICES

Technical Coordinator

•B.S. in Engineering, Chemistry, Physics or Life Sciences and one to three years' experience in health physics, radio chemistry or radio biology. Duties will involve liaison between the various research groups in a large nuclear research laboratory and the laboratory's Health Chemistry Department. This department furnishes an integrated package of engineering, monitoring, ventilation, transportation, and waste disposal services for safe handling of radioisotopes.

Please send confidential resume to
MR. W. F. KANE

LAWRENCE RADIATION LABORATORY

Berkeley, California

WANTED
MANUFACTURERS REPRESENTATIVES
Sought by growing manufacturer of neutron detection devices, sapphire metal windows and Dewars and other high vacuum ceramic metal assemblies.
Reuter-Stokes Electronic Components, Inc.
2149 Hamilton Avenue, Cleveland 14, Ohio

Engineer or Physicist
to head electronics dept of biological & medical research institute. PhD preferred. Knowledge of electronics & ability to design amplifiers & other circuits. Knowledge of radiation detectors desirable. Job involves design of new instruments & maintenance. Salary commensurate with education & exp. Send complete resume.
Sloan-Kettering Institute,
410 E. 68 St., New York, N.Y.

SALES REPRESENTATIVE

Spencer Chemical Company is seeking an experienced industrial sales representative for its Nuclear Fuels group. Preferably this man should have an engineering degree and it is imperative he have experience in the Nuclear industry. This position offers an excellent opportunity for growth into a sales management position. In reply send detailed resumé to:

Personnel Manager
Spencer Chemical Company
610 Dwight Building
Kansas City, Missouri

Additional Employment Advertising on page 125

INDEX TO ADVERTISERS

* AMF Atomics, A Division of American Machine & Foundry Co. 46, 47
* Allis-Chalmers 105
American Cystoscope Makers, Inc. 48
* American Smelting & Refining Co., Federated Metals Division.... 17
* American Tradair Corp., Ekco Electronics Ltd.....120
* Arapahoe Chemicals, Inc.....117
Atomic Energy of Canada Limited.109
* Atomics International, A Division of North American Aviation, Inc. 38, 52
Autoclave Engineers, Inc..... 89
* Babcock & Wilcox Company.... 1
* Barnstead Still & Sterilizer Co... 6
Bell Telephone Mfg. Co.....113
Boston Insulated Wire & Cable Co. 112
* Brooks & Perkins, Inc..... 98
* Byron Jackson Pumps, Inc..... 95
CPC Engineering Corporation...126
* Carboline Company..... 94
Carpenter Steel Company..... 49
* Central Research Laboratories, Inc. 2
* Charleston Rubber Company....126
* Columbia-Geneva Steel Division 10, 11
* Combustion Engineering, Inc...14, 15
* Crawford Fitting Company..... 39
* Delta Design, Inc..... 88
* Ex-Cell-O Corporation..... 87
Fluke Mfg. Co., Inc., John..... 85
Foxboro Company, The..... 83
* General Kinetics Corporation....125
Gordon Co., Claud S..... 86
Gray Tool Company..... 9
* Haws Drinking Faucet Co..... 94
* High Voltage Engineering Corporation 101
* Hughes Aircraft Company...48, 115
International Business Machines.. 99
* Internuclear Company, A Subsidiary of Petrolite Corp.....122
Joy Manufacturing Company.... 97
* Kearfott Division General Precision, Inc.....117
* Kewaunee Scientific Equipment..123
* Kollmorgen Corp..... 37
* Linde Company, Division of Union Carbide Corp.....103
* Lionel Electronic Laboratories, Formerly Anton Electronic Laboratories, Inc. 118
* Lockheed Nuclear Products Georgia Div.....3rd Cover
* Los Alamos Scientific Laboratory.106
* Martin Company, The..... 5
* McGraw-Hill Book Co.....121
* Midwest Piping, A Division of Crane Co..... 91
* Minneapolis-Honeywell 96
Nagle Pumps, Inc.....123
* National Lead Company.....34, 35
Newbrook Machine Corporation.108
* Nuclear Data, Inc..... 81
* Nuclear Enterprises Ltd.....119
* Nuclear Materials & Equipment Corp. 36, 88
* Nuclear Measurements Corporation 96
NUCLEONICS 93
NUCLEONICS WEEK.....111
Oak Ridge Technical Enterprises Corp. 103
Penberthy Instrument Co.....123
Pfizer & Co., Inc., Chas..... 43
Quartz & Silice..... 12
* RCA Electron Tube Div.....121
* RCA Service Company..... 7
* Radiation Counter Laboratories, Inc. 33
* Radiation Instrument Development Laboratory, Inc..... 42
Radiation Research Corporation.123
Radiation Technology, Inc.....110
* Radiochemical Centre, The.....116
* Reactor Experiments, Inc.....119
Research Incorporated.....113
Research Laboratories United Aircraft Corporation.....124
* Reuter-Stokes Electronic Components, Inc. 48
S.A.M.E.S. (S.A. De Machines Electrostatiques) 16
* Sandusky Foundry & Machine Co. 8
Smith Corporation, A. O.....40, 41
Stalker Corporation, The.....107
* Stokes Corporation, F. J..... 98
* Superior Tube Company..... 13
* Technical Measurement Corporation 45
* Tennessee Coal & Iron Division 10, 11
* United Nuclear Corporation..... 20
* U. S. Pipe & Foundry Co., Steel & Tubes Division.....18, 19
* United States Radium Corporation 107
* United States Steel Corporation 10, 11
* United States Steel Export Company 10, 11
* Victoreen Instrument Company 4th Cover
Westinghouse Atomic Power Division 44
* Westinghouse Electric Corporation 50, 51
Wiggins Oil Tool Co., Inc., E. B..109
* Worthington Corporation. 2nd Cover
Zirconium Corporation of America.117

*** See the advertisement in the November, 1960 issue of Nucleonics Buyers' Guide for complete line of products and services.**

•

PROFESSIONAL SERVICES.....123

CLASSIFIED ADVERTISING
F. J. Eberle, Business Mgr.

EMPLOYMENT OPPORTUNITIES 125, 127
MERCHANDISE (Used or Surplus New).....123
Atomic Energy of Canada Limited..127
Atomic Personnel Inc.....127
General Electric 127
Lawrence Radiation Laboratory.....127
Reuter-Stokes Electronic Components Inc. 127
Sloan-Kettering Institute 127
Spencer Chemical Co.....127

This index is published as a service. Every care is taken to make it accurate, but NUCLEONICS assumes no responsibility for errors or omissions.

NUCLEONICS ADVERTISING SALES REPRESENTATIVES

NEW YORK:
Donald J. Cassidy
500 Fifth Ave.
New York 36, N. Y.
OXford 5-5959

BOSTON:
Merrill J. Hosmer
McGraw-Hill Building
Copley Square
Boston 16, Mass.
COngress 2-1160

PHILADELPHIA:
Donald C. Knapp
Six Penn Center Plaza
Philadelphia 3, Pa.
LOcust 8-4330

CHICAGO:
Willis T. Smith
645 N. Michigan Ave.
Chicago 11, Ill.
MOhawk 4-5800

CLEVELAND:
Thomas K. Cogswell
55 Public Square
Cleveland 13, Ohio
SUperior 1-7000

LOS ANGELES:
Frederick R. Whitmore
1125 West Sixth St.
Los Angeles 17, Calif.
HUntley 2-5450

PORTLAND:
Scott Hubbard
Room 445, Pacific Bldg.
Yamhill Street
Portland 4, Oregon
CApital 3-5118

ATLANTA:
M. H. Miller
McGraw-Hill Pub. Co., Inc.
1375 Peachtree St., N.E.
Atlanta 9, Georgia
ATlanta 875-0523

DALLAS:
John G. Grant
McGraw-Hill Pub. Co., Inc.
901 Vaughn Bldg.
1712 Commerce St.
Dallas 1, Texas
Riverside 7-9721

HOUSTON:
Joseph C. Page
McGraw-Hill Pub. Co., Inc.
Prudential Bldg., W-724
Holcombe Blvd.
Houston 25, Texas
JAckson 6-1281

DENVER:
John W. Patten
McGraw-Hill Pub. Co., Inc.
Tower Bldg.
1700 Broadway
Denver 2, Colo.
ALpine 5-2981

LONDON:
Edward E. Schirmer
Dennis McDonald
McGraw-Hill Pub.Co.,Ltd.
34 Dover St.
London W1, England

FRANKFURT:
Stanley R. Kimes
McGraw-Hill Pub. Co., Inc.
85, Westendstrasse
Frankfurt/Main, Germany

GENEVA:
Michael R. Zeynel
McGraw-Hill Pub. Co., Inc.
2, Place du Port
Geneva, Switzerland

How should a nuclear rocket be launched ?

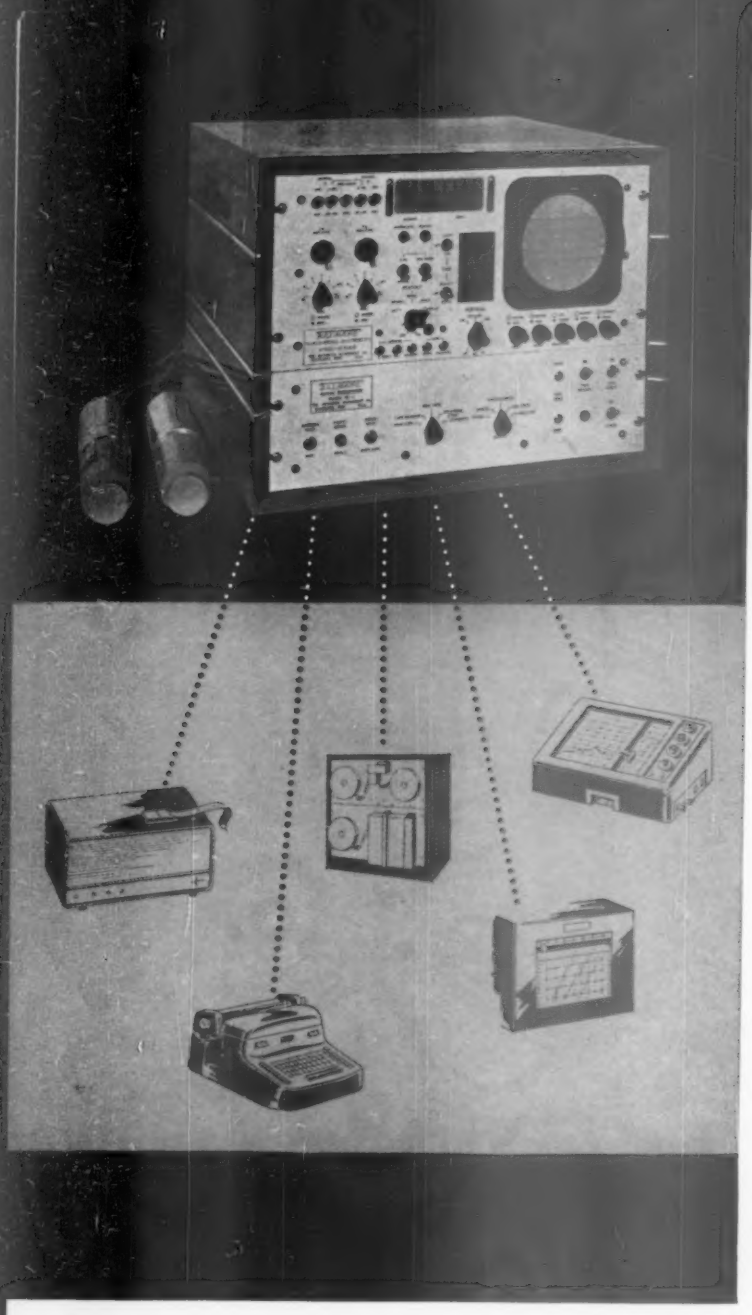
from ground

from second stage

from orbiting vehicle

We worked on this problem with the Missiles & Space Division of Lockheed under the National Aeronautics and Space Administration's RIFT program. Our specific assignment: find the safest way to use nuclear propulsion in space. To that end we made an analysis of all parameters—including the buildup and disposal of fission products, re-entry hazards, and emergency countermeasures.

LOCKHEED GEORGIA



Now Building
MULTI-DIMENSIONAL ANALYZERS . . .

Victoreen

Victoreen, the first name in radiation measurement, is delivering the last word in multi-channel analyzers—the Tullamore-designed Model ST-200D

- 200 or 400 Channel ferrite core memory
- Dual input—Simultaneous data accumulation
- Subgrouping and bi-directional logic
- Parallel or serial readout—Wide selection of readout devices
- Visual display and readout—Linear, log or both simultaneously
- Simultaneous linear and log plot

A-4003A

. . . and
400 and 800 CHANNEL
(1-8 Inputs)
"M" SERIES

Service by
RCA SERVICE COMPANY
A Division of Radio Corporation of America

V I C T O R E E N
5806 HOUGH AVENUE • CLEVELAND 3, OHIO
EXPORT: 240 WEST 17TH ST. • NEW YORK 17, NEW YORK